COMPUTER AIDED PROCESS PLANNING SYSTEM FOR AXISYMMETRIC COMPONENTS

by

Sudip Kumar Mazumder

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

March 1994

COMPUTER AIDED PROCESS PLANNING SYSTEM FOR AXISYMMETRIC COMPONENTS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
Master of Technology

by

Sudip Kumar Mazumder

to the

Department of Mechanical Engineering

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

March, 1994

CERTIFICATE

11.3.94

It is certified that the work contained in the thesis titled "Computer Aided Process Planning System for Axisymmetric Components", by Sudip Kumar Mazumder, has been carried out under our supervision and that this work has not been submitted elsewhere for a degree.

(Dr Kripa Shankar)

Professor,
Industrial and Management
Engineering Programme,
I.I.T. Kanpur 208 016.

(Dr M. K. Muju)

Professor,
Department of Mechanical
Engineering,
I.I.T. Kanpur 208 016.

March, 1994

ACKNOWLEDGEMENTS

I feel great pleasure in expreesing my heartfelt thanks to Prof. M.K. Muju and Prof. Kripa Shanker for their expert guidance, valuable suggestions, useful criticisms and constant encouragements throught the course of my thesis work.

My sincere thanks are also due to all my friends who made my stay at IIT Kanpur a pleasant and memorable one. In particular I would like to thank Sanjay Sharma and Yogendra Chordia for everything they have done for me.

Finally, I would like to thank all my teachers for teaching the courses at which they excel.

(SUDIP KR·MAZUMDER)

March 1994

ABSTRACT

In the present thesis an attempt has been made to design and implement a CAPP system for the manufacturing of axisymmetric parts. The system recognizes the features from the part input, selects the blank from which the part is to be machined, selects and sequences the appropriate machining operations, generates the NC part program of the part and then shows the simulation of the cutter path on the graphics screen. The system is capable of handling a wide gamut of features (including complex functional form features) and machining operations. Nearly all possible machining operations that are performed on an NC turret are handled by the system. The part input can be given either interactively, data file, or by drawing the part in AutoCAD.

The system has been implemented on an IBM compatible PC-XT/AT. The entire source code is generated in TURBO C. The data bases used by the system are stored in files. The NC part programs have been tested on a NC Turret with a FANUC controller. The system is menu based with multiple hierarchical levels so that the end user finds it convenient to interact with the system.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

center_x	X co-ordinate of the center of a circular arc	mm
center_y	Y co-ordinate of the center of a circular arc	mm
curve( )	Polynomial function	
D	Diameter of the blank	mm
feature(i)	Feature no i	
f_{max}	Maximum allowable feed on a particular machine	mm/rev
L	Length of the blank	mm
n	Total no of features	
r	Radius of a circular arc	mm
N_{max}	Maximum allowable speed on a particular machine	rpm
N_{min}	Minimum allowable speed on a particular machine	rpm
U	Union operator	
x_1	Starting x co-ordinate of a feature	mm
x_2	End x co-ordinate of a feature	mm
y_1	Starting y co-ordinate of a feature	mm
y_2	End y co-ordinate of a feature	mm
y_{maxi}	Maximum y co-ordinate of the i^{th} feature	mm
$(y_{max})_i$	Maximum y co-ordinate counted from the end of the workpiece up to the i^{th} feature	mm
$\neq$	Not equal to operator	
>	Greater than operator	
<	Less than operator	
+	Addition operator	
-	Subtraction operator	
=	Equality operator	

CHAPTER I

INTRODUCTION

Recent developments in the computer technology have tremendously influenced the decision making process in the manufacturing systems. The two most important tools that aid in the decision making process in the manufacturing systems are computer aided design (CAD) and computer aided manufacturing (CAM). CAD and CAM are concerned principally with the engineering functions in design and manufacturing respectively. Product design, engineering analysis and documentation of the design (e.g drafting) represent engineering activities in the design function while computer aided process planning, material requirement planning, production scheduling and computer aided process control represent engineering activities in manufacturing function.

With conventional procedures practiced for many years in the industry, engineering drawings were prepared by the draftsman and then used by manufacturing engineers to develop the process plan (i.e the route sheet). The activities involved in the designing the product were essentially separated from the activities associated with manufacturing. This many a times resulted into duplication of efforts by design and manufacturing personnel and quite often into inconsistency and conflicts. With an integrated CAD/CAM system such unnecessary and undesirable conflicts and wastage are done away with by establishing a link between product design and manufacturing engineering. Such an integrated system not only automates certain phases of design and manufacturing, it also automates the transition from design to manufacturing. Process planning is an important functional link

between design and manufacturing as it aims to eliminate the possible inconsistencies and conflicts.

1.1 PROCESS PLANNING AND COMPUTER AIDED PROCESS PLANNING

Process planning determines the best sequence of machining operation to produce a part. In general three steps are required: selection, calculation, and documentation. For a given part, selection involves the determination of appropriate processes, machine tools, tools, operations and their sequences. Calculation must be done to obtain the optimal machining data, such as speed, feed rate, depth of cut, number of passes and so on, to minimize the total machining cost and maximizing the production rate. It is obvious that selection and calculation steps are interdependent in a sense that decision of one influences those of the other. As a last step, a route sheet is produced documenting the results of selection and calculation. To execute these steps of process planning, a large number of inputs are required regarding geometrical and manufacturing characteristics of a parts, capability of machine tools, tool specifications, and so on.As a consequence of the rapidly changing behavior of product characteristics of parts and development of new processes, machine tools, materials etc , the inputs to the process planning change over time, making the decision problems often unstructured. Thus the three steps of process planning have to be continuously reviewed and modified in view of changing manufacturing environment. This has led to the emergence of computer-aided process planning (CAPP). The CAPP system through its inherent iterative characteristics provides a transparent

regarded as a CAD/CAM integration tool.

There are two major approaches to CAPP namely variant and generative. This two approaches differ mainly on the basis of content of dynamic elements in the inputs to the process planning decisions. In the variant type, all parts produced are classified and grouped under group technology concepts to form part families, for each part family standard process plans are established. For a given part, using its classification code, the corresponding standard part family is retrieved and subsequently modified to suit the part. In the generative type, for a given part, the process plan is created by the computer employing a set of algorithms. Such a system synthesizes the design of optimum process sequence based on analysis of part geometry, material and other factors.

Of the two approaches the generative type of process planning have good potential because it can be used for any part designs to produce the route sheet. But to produce a generative process plan is not an easy task because there are no standard algorithms and methods, again most of the information or knowledge is empirical and, to a large extent depends on the type of industry, available machine tools, and cutting tools. In the present system an attempt has been made to produce generative process plan for axisymmetric components.

1.2 LITERATURE REVIEW

There are several reviews of CAPP systems presently available (Steuden[1], Atling and Zang[2]). The latest one by Atling and Zang[2] gives the detailed list of CAPP systems developed up to 1989. According to them AI (Artificial Intelligence) provides better planning and control facility and

developed for process planning of rotational parts by Kripa Shanker and Prasad[9] extensive data base is used for the selection of cutting conditions, tools, and cutting fluids. This system is also capable of calculating the total machining time and the time for which each tool is required. This system has used a feature based approach but the number of features considered is only nine. A nearly similar work has been done recently by Jasti et al[10].

With the growing popularity of feature based approach in CAPP a number of significant works have been done recently. Batanov et al[11] have developed and implemented an application software for the manufacturing of rotational parts using the feature base approach. The main shortcoming of this software is that extensive process planning module has not been developed.

1.3 SCOPE OF THE PRESENT WORK

In the present thesis an attempt has been made to design and implement a generative CAPP system for the manufacturing of axisymmetric components. The proposed CAPP system has the following modules.

(1) Feature recognition module.

(2) Blank and machining parameter selection module.

(3) Operation selection and sequencing module.

(4) NC part program generation module.

(5) Machining simulation module.

The developed system accepts the input data provided by the user regarding the part geometry of the job to be machined, specifications of the machine tool on which he/she wants to machine the job, specifications for machining the feature

SPECIAL_CURVE and the simulation speed. The system then processes these data to recognize the features making up the part, selects the size of the blank from which the job is to be machined, selects the optimum machining parameters, sequences the machining operations to be performed on the blank for producing the job or workpiece, generates the nc part program for machining the job and as a last step shows the simulation of the cutter path on the graphics screen. The flow chart of the developed system is shown in Fig 1.1.

1.4 ORGANIZATION OF THE THESIS

Chapter I gives a brief introduction of process planning and computer aided process planning (CAPP). Then the review of the previous works done in this field has been given. Lastly this chapter gives a brief insight of the present work and its scope.

Chapter II deals with feature recognition. In the starting portion of the chapter the advantages and classification of feature based approach has been discussed. After this the reason for choosing feature recognition subset of feature based design has been discussed. The rest of the chapter deals exclusively with the features that can be recognized by the system and the machinability checks that has been incorporated to wean out spurious features.

Chapter III describes the blank and machining parameters selection algorithm in necessary details.

Chapter IV deals with the operation selection and sequencing algorithm.

Chapter V describes the methodology used for generating the NC part program and the suitable M and G codes.

Chapter VI deals with the present simulation systems that are available for manufacturing at the beginning of the chapter. After this the simulation system that has been developed is discussed.

Chapter VII deals with the software system that has been developed. The options available for inputting the various data is discussed and to demonstrate the various features of the system an illustration is given.

Chapter VIII gives the conclusions and limitations of the present work and the suggestions for future work.

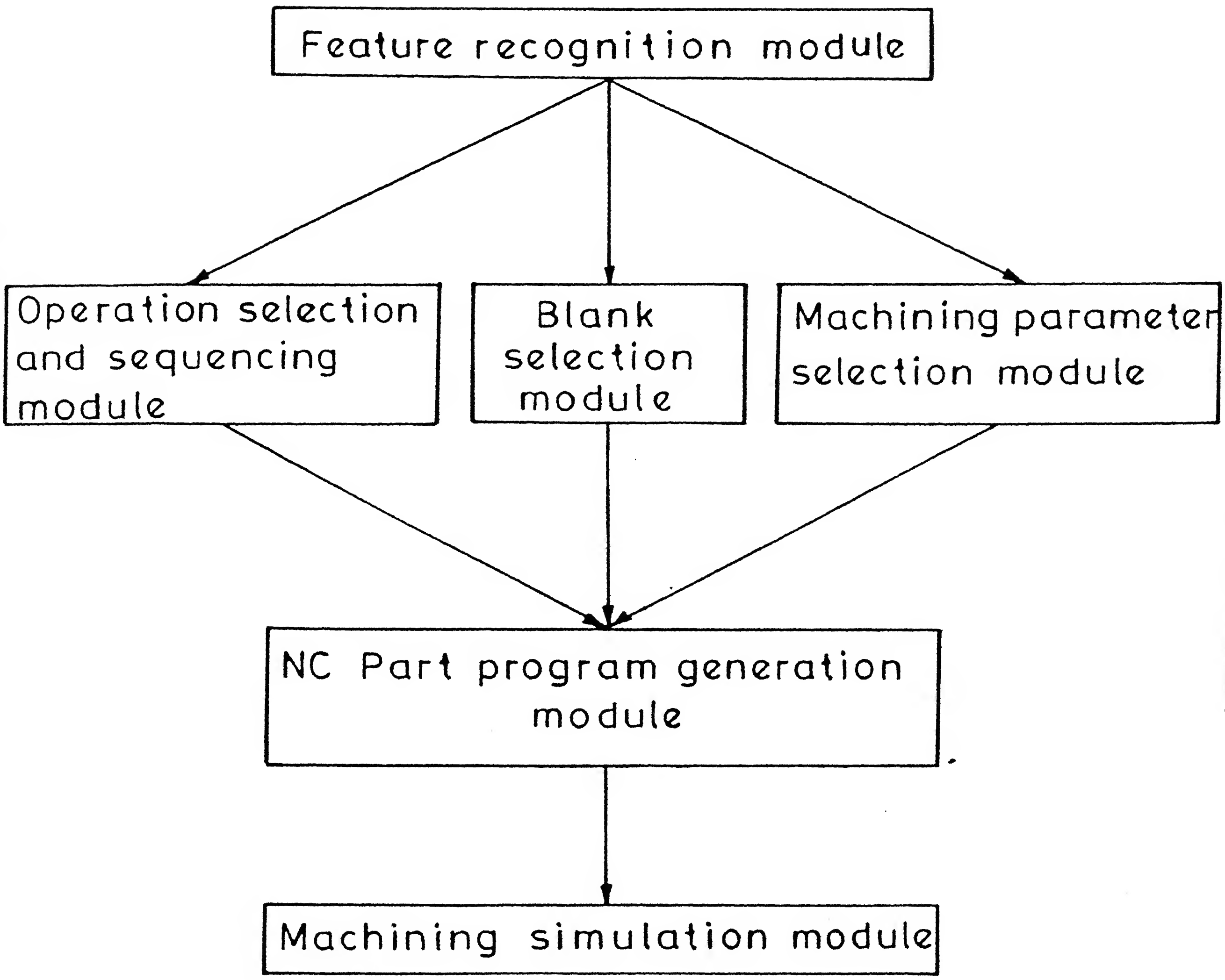


Fig 1.1 Architecture of the developed CAPP System

CHAPTER II

FEATURE RECOGNITION

A CAD system, typically provides part topology and geometrical information, for generating manufacturing plans. Part geometry can be divided into geometric entities called features. Feature can be defined in many ways, a broad definition being that it is the region of interest on various surfaces of a part that is to be produced. A more comprehensive definition of feature would be that it represents a collection of entities in an intelligent form that matches the way engineers think and hence provide information at a higher conceptual level than the purely geometrical representation like lines, arcs, and texts. Features allow both design and manufacturing engineers to perform their separate but interrelated tasks using a language they have always shared, the language of features such as "holes", "face" etc. So the feature based approach is one of the most promising way of reaching the absolutely necessary goal of integrating all CIM subsystems in general, and its two major subsystems design and manufacturing, in particular.

2.1 ADVANTAGES OF FEATURE BASED APPROACH

The main reason for the immense popularity of the feature based approach are:

(1) Data based reasons.

(2) Knowledge based reasons.

(3) User oriented reasons.

2.1.1 Data Based Reasons: CIM is a large and complex domain. It embraces many related but different processes or activities:

ometric modelling and design, engineering analysis and lculations, process planning, manufacturing, manufacturing esource planning, quality control, assembly etc. For each of hese subsystems the data are very specific and, as a rule, ncomplete from the point of view of other subsystems. In this ase the feature based approach allows the objects of interest to e represented in a generic form and new features to be added nd/or removed according to the requirement of the corresponding ubsystems during the process of objects manipulation.

.1.2 Knowledge Based Reasons: Even without an in depth analysis of the CIM subsystems, it can be observed that the three basic inds of knowledge, namely declarative, procedural and heuristic are used intensively in the design, development and management. The main problem here is how this knowledge is derived from available data and used properly. In this case the feature based approach allows a real data and knowledge integration simply because the feature representation forms, in fact, is a knowledge representation scheme. Declarative, procedural and heuristic knowledge can be expressed and processed relatively easily.

2.1.3 User Oriented Reasons: One of the most important requirement of the integration of CIM subsystems is that the respective software systems should be centered around the end user. In other words the end user has to be allowed to think, input data, and get the intermediate and final results in as much more natural way as possible. The data and knowledge representation using the feature based approach corresponds directly to this natural way of thinking because of the engineering meaning of the features.

2.2 CLASSIFICATION OF THE FEATURE BASED APPROACH

Feature based approach involves (1)feature based design, (2) automatic feature extraction or recognition and (3)feature identification.

2.2.1 Feature Based Design

In feature based design approach, the features are predefined according to the given application and stored in a feature library. The applicability of the feature based design approach has been restricted by a number of serious drawbacks. The drawbacks are stated below.

Firstly the feature of the part designed at the selected application mode can be meaningless for another application. Secondly additional feature extraction or mapping process is necessary to generate the new features understandable by anotherapplication system. Lastly in most cases this approach does not provide complete geometric information of a part.

2.2.2 Automatic Feature ExtractionOr Recognition

In the automatic feature extraction approach, the features are extracted from the completed part design. The feature extraction is performed by searching the same pattern with the templates specified over the part boundary data.

The main disadvantage of the feature extraction approach is the searching problem. The feature template in the knowledge base are tried out one by one to be matched with the same pattern of boundary data. Since both the feature and the part boundary data are represented as graphs, the extraction procedure is expensive.

2.2.3 Feature Identification

In the feature identification approach the features are

defined manually. A user identifies the features from the graphic display or the blue print of a part.

The applicability of the feature identification technique is restricted by the errors made by the user. This is a very primitive method and is not generally used.

So we see that the feature based approach is most suitable method of representing the knowledge base of a part. In the present system the second subset (i.e feature recognition or extraction approach) of the feature based approach has been used since the feature templates are very simple and considerably less time and money is required for searching.

2.3 FEATURE RECOGNITION MODULE

The architecture of the proposed feature recognition module is shown in Fig 2.1. In the part geometry input stage the user specifies the end point co-ordinates of the features. The data structure used for storing the above data is shown in Fig 2.2.

The work surface can be considered to be made up of a finite number of features. In the proposed work a number of such features have been identified (Fig 2.3a and 2.3b). These features can be broadly classified into two categories.

1) Simple features

2) Special features

The features that come under the first category can be recognized directly from the end point co-ordinates specified by the user. A decision table is prepared in the IF-THEN format for the correct recognition of the features. The format is illustrated

IF (mathematical relation(Fig 2.3a) based on coordinates) THEN (feature is ......).

In the second category the features cannot be completely identified from the knowledge about the end point co-ordinates. certain additional data are to be provided for complete identification of these features. The complete description of the two categories of features are given in Fig 2.3a and 2.3b.

One of the special feature is the SPECIAL_CURVE. The SPECIAL_CURVE is a very powerful tool as it can be used to represent complex axisymmetric objects with functional form features such as turbine rotor and subsequently machine them on the CNC lathe. So objects that were previously cast can now be machined effectively, though the effectiveness is to some extent dependent on the resolution of the machine.

The information of the SPECIAL_CURVE is stored in a link-list. the construction of the link-list is shown in Fig 2.4. As can be seen the link-list used is a linear one, the number of such link-lists that are required for the special curve depends on the number of terms in the polynomial used to specify the curve. As already shown in Fig 2.3b the curve is accepted in the form

$$y = \text{curve}(\ x\ ) = \ldots + ai\ x\ Fi(x) + \ldots$$

Here,

y = y co-ordinate of any point on the curve.

x = x co-ordinate of any point on the curve.

The restriction on x is $x_1 =< x <= x_2$

x_1= Starting x co-ordinate of the feature.

x_2= End x co-ordinate of the feature.

curve( ) = polynomial with n terms.

ai = Coefficient of the i^{th} term of the polynomial.

It is a constant.

$Fi(x)$ = Function of x which makes up the i^{th} term of the polynomial. The detailed list of the functions are given in chapter VII.

The intermediate points on the selected curve are found out using the resolution desired by the user and the equation of the curve. The resolution is used to find out intermediate x co-ordinates and the equation of the curve is then used to find the intermediate y co-ordinates. The intermediate points are stored in a link-list shown in Fig 2.2. After the storing is over the memory assigned for storing thé equation of the curve is set free.

Before a feature is finally accepted and appended to the data base it has to satisfy a number of conditions.The conditions are expressed in the form of IF-THEN rules in the actual program. The form of the IF-THEN rules used is shown below.

IF(condition)

THEN(feature is unmachinable)

These conditions acts as effective filters which help the system in weaning out any spurious parts.

The conditions are elaborated below.

CONDITION 1

IF(feature(1) $\neq$ UP_FACE)

THEN(the feature(1) is unmachinable)

The above condition is only applicable when the parting off is used as the final operation.

CONDITION 2

IF($x_{1feature(1)} \neq 0.0$)

THEN(the feature(1) is unmachinable)

CONDITION 3

$IF\{\ y_{1feature(1)} \neq 0.0\ \}$

THEN{ the feature(1) is unmachinable }

CONDITION 4

$IF\{\ x_{1feature(i)} \neq x_{2feature(i-1)}\ \}$

THEN{ the feature(i) is unmachinable }

Here i ranges from 2 to n.

CONDITION 5

$IF\{\ y_{1feature(i)} \neq y_{2feature(i-1)}\ \}$

THEN{ the feature(i) is unmachinable }

Here i ranges from 2 to n.

CONDITION 6

$IF\{\ x_{2feature(i)} < x_{1feature(i)}\ \}$

THEN{ the feature(i) is unmachinable }

Here i < n - j.

j = no of features which are either INT_THREAD(LH), orINT_THREAD(RH) or HOLE.

CONDITION 7

$IF\{\ (\ x_1 = x_2\ )\ and\ (\ y_1 = y_2\ )\ \}$

THEN{ the feature is unmachinable }

The above condition is applicable for any feature.

CONDITION 8

$IF\{\ (\ y_{1feature(i)} = 0.0\ )OR(\ y_{2feature(i)} = 0.0\ )\ \}$

THEN{ the feature(i) is unmachinable }

Here i ranges from 2 to n-1.

CONDITION 9

When feature(i) is FORM_UP or FORM_DOWN

$IF\{\ (\ x_2 - x_1\ )^2 + (\ y_2 - y_1\ )^2 > 2 \times r\ \}$

THEN{ the feature(i) is unmachinable }

Figure for this case is shown in Fig 2.5a

CONDITION 10

When feature(i) is FORM_UP

IF{ (y_1 < center_y) OR (y_2 < center_y) }

THEN{ the feature(i) is unmachinable }

Figure for this case is shown in Fig 2.5b

CONDITION 11

When feature(i) is FORM_DOWN

IF{ (y_1 > center_y) OR (y_2 > center_y) }

THEN{ the feature(i) is unmachinable }

Figure for this case is shown in Fig 2.5c

CONDITION 12

IF[{ feature(i) U feature(i - 1) }

results in the cases shown in Fig 2.6]

THEN{ the feature(i) is unmachinable }

CONDITION 13

When feature(i) is PARALLEL_KNURL or DIAMOND_KNURL or

EXT_THREAD(LH) OR EXT_THREAD(RH)or INT_THREAD(LH)

or INT_THREAD(RH)

IF{ (y_2 > y_1)or(y_1 > y_2) }

THEN{ the feature(i) is unmachinable }

CONDITION 14

IF{ feature(i) is PARALLEL_KNURL or DIAMOND_KNURL or

EXT_THREAD(LH) OR EXT_THREAD(RH)

IF{ (x_2 < x_1) }

THEN{ the feature(i) is unmachinable }

CONDITION 15

When feature(i) is INT_THREAD(LH) or INT_THREAD(RH)

IF{ ($x_2 > x_1$) }

THEN{ the feature(i) is unmachinable }

CONDITION 16

When feature(i) is SPECIAL_CURVE

IF{ ($y_1 \neq y_{1'}$) or/and ($y_2 \neq y_{2'}$) }

THEN{ the feature(i) is unmachinable }

Here,

$y_{1'}$ = curve(x_1)

and $y_{2'}$ = curve(x_2)

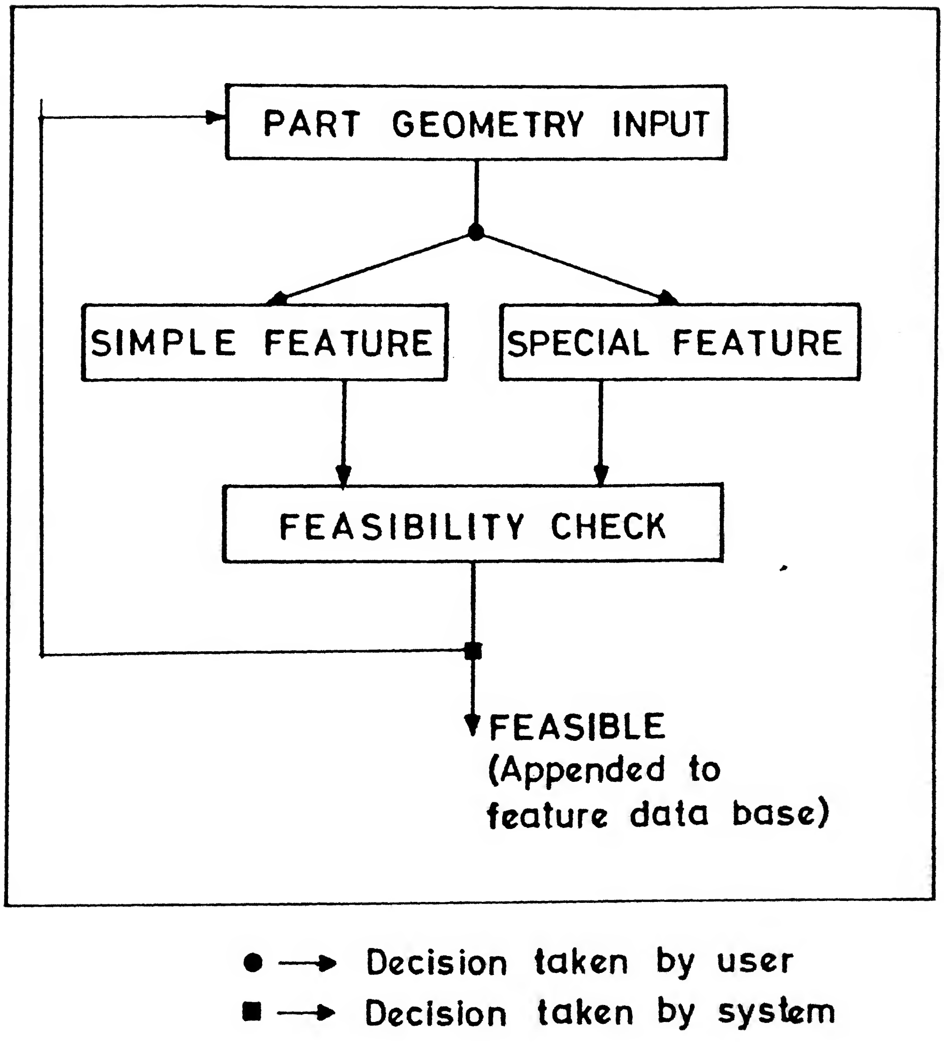


Fig 2.1 Architecture of the Feature recognition module

Cord1	Cord2	Reso	

pointer pointing to the parent structure

Fig 2.2 Data structure for storing the necessary information of the features

Coeff_p	Power_p	Root_o	Root_num	

pointer pointing to the parent structure.

Fig 2.4 Construction of the link list for storing the necessary information of the feature SPECIAL_CURVE

EXPLANATION OF THE SYMBOLS USED IN Fig 2.2 and 2.4

SYMBOL	EXPLANATION
cord1	structure that stores the co-ordinates of the leading end of the feature
cord2	structure that stores the co-ordinates of the lagging end of the feature
reso	resolution specified by the user
coeff_p	coefficient of a term of the polynomial
power_p	power to which the function F(x) of a term of the polynomial is raised
root_o	order of the root if the function F(x) happens to be of type root
root_num	no of terms inside the root

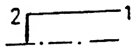
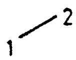
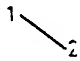
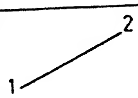
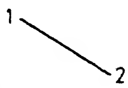
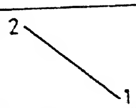
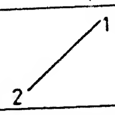
Feature	Geometric form	Geometric data required	Mathematical criterion
Face (i) Up-Face		x_1, y_1, x_2, y_2	$x_1 = x_2$ and $(y_2 - y_1) > 0$
(ii) Down-Face		x_1, y_1, x_2, y_2	$x_1 = x_2$ and $(y_1 - y_2) > 0$
CYL		x_1, y_1, x_2, y_2	$y_1 = y_2$ and $(x_2 - x_1) > 0$
Hole		x_1, y_1, x_2, y_2	$y_1 = y_2$ and $(x_1 - x_2) > 0$
Chamfer (i) Up-Chamfer		x_1, y_1, x_2, y_2	$c \geq (x_2 - x_1) > 0$ and $(y_2 - y_1) > 0$
(ii) Down Chamfer		x_1, y_1, x_2, y_2	$c \geq (x_2 - x_1) > 0$ and $(y_1 - y_2) > 0$
Ext. Taper (i) Up-Extaper		x_1, y_1, x_2, y_2	$(x_2 - x_1) > 6$ and $(y_2 - y_1) > 0$
(ii) Down-Extaper		x_1, y_1, x_2, y_2	$(x_2 - x_1) > 6$ and $(y_1 - y_2) > 0$
Int. Taper (i) Up-Initaper		x_1, y_1, x_2, y_2	$(x_1 - x_2) > 0$ and $(y_2 - y_1) > 0$
(ii) Down-Initaper		x_1, y_1, x_2, y_2	$(x_1 - x_2) > 0$ and $(y_1 - y_2) > 0$

Fig. 2·3a Simple features

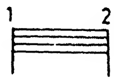
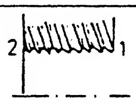
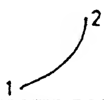
Feature	Geometric form	Geometric data required	Mathematical criterion
KNURL (i) Parallel Knurl		x_1, x_2, y_1, y_2	$y_1 = y_2$ and $(x_2 - x_1) > 0$
(ii) Diamond Knurl		x_1, x_2, y_1, y_2	$y_1 = y_2$ and $(x_2 - x_1) > 0$
FORM (i) Form-up		x_1, x_2, y_1, y_2 r	$(x_2 - x_1)^2 + (y_2 - y_1)^2 \leq 2r$ $y_1 >$ center-y $y_2 >$ center-y
(ii) Form-Down		x_1, x_2, y_1, y_2, r	$(x_2\ x_1)^2 + (y_2 - y_1)^2 \leq 2r$ $y_1 <$ center-y $y_2 <$ center-y
Ext. Thread (i) Ext. Thread (RH)		x_1, x_2, y_1, y_2, p	$y_1 = y_2$ and $(x_2 - x_1) > 0$
(ii) Ext. Thread (LH)		x_1, x_2, y_1, y_2, p	$y_1 = y_2$ and $(x_2 - x_1) > 0$
Int. Thread (i) Int. Thread (RH)		x_1, x_2, y_1, y_2, p	$y_1 = y_2$ and $(x_1 - x_2) > 0$
(ii) Int. Thread (LH)		x_1, x_2, y_1, y_2, p	$y_1 = y_2$ and $(x_1 - x_2) > 0$
Special curve		x_1, x_2, y_1, y_2 and each term of polynomial y=curve(x)	y_1 = curve (x_1) y_2 = curve (x_2)

Fig. 2·3b Special features

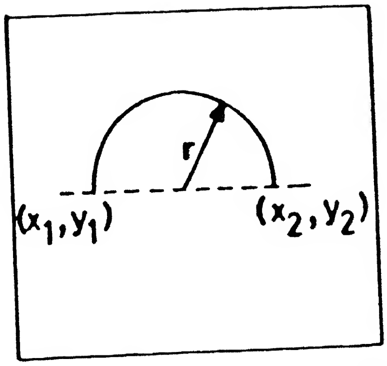


Fig.2.5a Unmachinable feature (condition 9 satisfied)

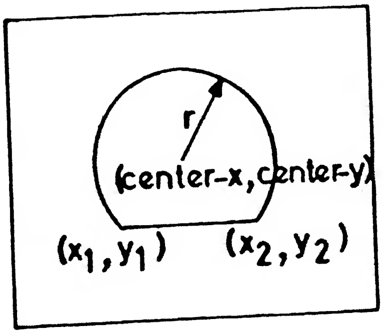


Fig.2.5b Unmachinable feature (condition 10 satisfied)

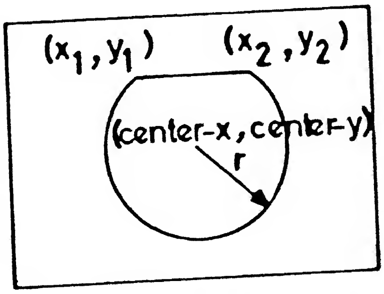


Fig.2.5c Unmachinable feature (condition 11 satisfied)

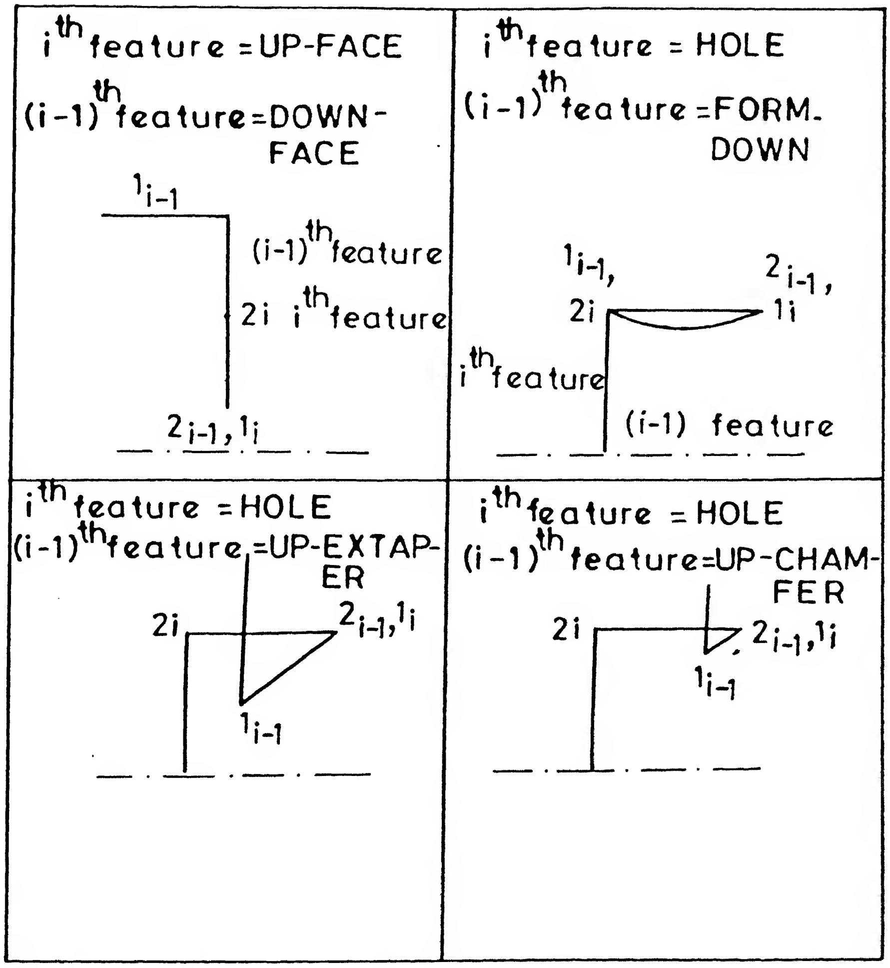


Fig 2.6 Features unmachinable due to their position with respe
to the corresponding previous features

CHAPTER III

SELECTION OF BLANK AND MACHINING PARAMETERS

The selection of the blank and machining parameters in a CAPP system depends to a large extent on the data base available with the particular system, so it is not possible to design standard algorithms for the selection of the same.

In the present system suitable algorithms have been developed for the selection of the blank size and the machining parameters keeping in view the data base available. The above mentioned algorithms has been discussed in details in the following sections.

3.1 BLANK SELECTION MODULE

This module selects the appropriate blank size by finding out the minimum size cylinder enveloping the given part geometry. This module also takes into consideration the maximum size of the blank that can be held on the available machine tool. The details about the algorithm developed for selecting the appropriate blank size is discussed below.

Let,

X^t_{max} = Maximum possible travel of the tool along x axis on a particular machine tool.

Y^t_{max} = Maximum possible travel of the tool along y axis on a particular machine tool.

X^j_{max} = Maximum dimension of the job along x axis.

Y^j_{max} = Maximum dimension of the job along y axis.

L = Length of the blank from which the job is to be machined.

D = Diameter of the blank from which the job is to be machined.

X^t_{max} and Y^t_{max} are actually machine specifications which are acquired by the system through timely interaction with the user. These information are stored by the system. The data structure used for storing these information is shown in Fig 3.1. The value of X^j_{max} and Y^j_{max} are found out from the dimensions of the component as specified by the user in the feature recognition module.

The selection is done according to the following IF-THEN -ELSE rule.

IF((X^t_{max} >= L) and (Y^t_{max} >= D/2))

THEN(the component is selected for machining on the provided machine tool)

ELSE(the component is rejected, and another machine tool has to be tried)

L and D of the blank are selected depending on the tolerance desired by the user. The tolerance depends on the dimensions of of the bar stock available with the user.

$L = X^j_{max}$ + tolerance on length.

$D = 2 \times Y^j_{max}$ + tolerance on diameter.

3.2 FEED, SPEED AND COOLANT SELECTION MODULE

This module selects the appropriate feed speed and coolant for each machining operation that takes place on the blank for producing the desired workpiece.

The details about the algorithm developed for selecting the appropriate speed, feed and coolant for each machining operation is discussed below.

The relevant information about the machine tool i.e maximum speed, minimum speed, maximum feed it supports, and the information about the component or workpiece material are acquired by the system through timely interaction with the user. Except for the component material all other information are stored by the system. The data structure used for storing these vital information has already been shown in Fig 3.1. The list of materials from which the user has to make the choice of the workpiece material is given in Table 3.1. Now for each machining operation the values of the speed and feed are picked from the corresponding data bases in accordance with the combination of the tool and workpiece material. The system is exclusively designed to handle two tool materials namely H.S.S and Cemented Carbide.

Let,

N_{max} = Maximum speed supported by the machine tool in r.p.m.

f_{max} = Maximum feed supported by the machine tool in mm/rev.

N_h = Speed for the combination of H.S.S tool material and selected workpiece material in r.p.m.

f_h = Feed for the combination of H.S.S tool material and selected workpiece material in mm/rev.

N_c = Speed for the combination of Cemented Carbide tool material and selected workpiece material in r.p.m.

f_c = Feed for the combination of Cemented Carbide tool material and selected workpiece material in mm/rev.

$\delta = N_c - N_h$

The rule for choosing the appropriate speed and feed can be expressed by the following IF-THEN statements.

IF{ (N_c <= N_{max}) and (f_c <= f_{max}) and ($\delta > 0$) }

or IF[(N_c <= N_{max}) and (f_c <= f_{max}) and ($\delta < 0$)

and{ (N_h >= N_{max}) and/or (f_h >= f_{max}) }]

THEN{ Cemented Carbide is chosen as tool material and the speed and feed selected are N_c and f_c respectively. }

If the above mentioned rule fails then the next rule used to evaluate the tool material isstated below.

IF{ (N_h <= N_{max}) and (f_h <= f_{max}) }

THEN{ H.S.S is chosen as the tool material and the speed and feed selected are N_h and f_h respectively }

In case the above mentioned rule also fails then the user is informed that suitable speed and feed were not selected. The default values used in this case is zero.

The coolant is selected from the data base in accordance with the work material specified. The system is capable of recommending more than one coolant for a particular machining operation if provision exists for the same.

X_max	Y_max	Speed_max	Speed_min	Feed_max	Type_toler

Toler	Type_interp	Speed_simu

Fig 3.1 Data structure for storing the specifications

Explanation of the terms used in this figure

X_max(X^{t}_{max}) = Maximum allowable travel of tool in x direction(mm) on a particular machine tool.

Y_max(Y^{t}_{max}) = Maximum allowable travel of tool in y direction(mm) on a particular machine tool.

Speed_max (N_{max}) = Maximum allowable speed(r.p.m) on a particular machine tool.

Speed_min (N_{min}) = Minimum allowable speed(r.p.m) on a particular machine tool.

Feed_max(f_{max}) = Maximum allowable feed(mm/rev) on a particular machine tool.

Type_toler = Type of tolerance the user desires ie either intol or outtol.

Toler = Value of tolerance(mm) specified by the user in

Type_interp = Type of interpolation the user desires for machining of SPECIAL_CURVE i.e either straight line interpolation or circular interpolation.

Speed_simu = Simulation speed desired by the user i.e either high, medium or low..

CHAPTER IV

OPERATION SELECTION AND SEQUENCING

One of the vital requirement for developing a CAPP system is to choose and sequence the appropriate machining operations for producing the desired workpiece from the given blank.

4.1 OPERATION SELECTION AND SEQUENCING MODULE

This module selects and sequences the suitable machining operations for producing the finished job from the blank. The algorithm that has been developed and implemented for this purpose is stated below.

The first machining operation that takes place on the workpiece is facing. The facing operation removes the excess material at the end of the workpiece.

Let,

Q = Amount of material removed in the facing operation in mm^2.

X^j_{max} = Maximum dimension of the job along x axis.

L = Length of the blank from which the job is to be machined.

D = Diameter of the blank from which the job is to be machined.

So, $Q = (L - X^j_{max}) \times (D/2)$.

The second machining operation that takes place on the workpiece is turning. The conventional IF-THEN rule is used for select the features that are to be turned. The rule is stated below.

IF($Y_{maxi} >= (Y_{max})_{i+1}$)

THEN(turn the feature)

and the value of $(Y_{max})_i = Y_i$

If the above rule is not satisfied then the feature is turned to the value of $(y_{max})_{i+1}$.

Here i $= n - j$ to 2.

y_{maxi} = Maximum y co-ordinate of a feature.

$(y_{max})_{i+1}$ = Maximum y co-ordinate up to and including the $(i+1)^{th}$ feature starting from the end.

Where j = No of DOWN_PLANE, HOLE, INTERNAL_TAPER(LH) or INTERNAL_TAPER(RH) at the end of the job.

The definition of y_{maxi} and $(y_{max})_{i+1}$ are valid throughout the rest of this section.

There are certain special cases of the above rule. These special cases are discussed below.

Case 1

If the i^{th} feature is DOWN_TAPER or DOWN_CHAMFER and

IF[{ y_{maxi} >= $(y_{max})_{i+1}$ } and { $y_{2i} < (y_{max})_{i+1}$ }]

THEN { the feature is not turned. The tool path in this case is shown in Fig 4.1a }

Here y_{2i} = y co-ordinate of the leading end of the i^{th} feature. The definition of y_{2i} is valid through the rest of the section.

Case 2

If the i^{th} feature is DOWN_FACE and

IF[{ y_{maxi} >= $(y_{max})_{i+1}$ } and { $y_{2i} < (y_{max})_{i+1}$ }]

THEN { the feature is turned from $(y_{max})_{i+1}$ to y_{maxi}. The tool path in this case is shown in Fig 4.1b }

Case 3

If the i^{th} feature is FORM_UP or SPECIAL_CURVE and

IF { $y_{maxi} >= (y_{max})_{i+1}$ }

THEN{ the feature is not turned. Then tool path in this case is shown in Fig 4.1c }

Case 4

If the i^{th} feature happens to be FORM_DOWN and

IF { $y_{maxi} >= (y_{max})_{i+1}$ }

THEN{ the feature is not turned. The tool path in this case is shown in Fig 4.1d }

The next machining operation that takes place on the workpiece is grooving depending on rule stated below in IF-THEN form

IF { $y_{maxi} < (y_{max})_{i+1}$ }

THEN{ grooving operation takes place on the workpiece starting from the i^{th} to the $(i - v)^{th}$ feature.}

Here v = search(i)

Where search (i) is a function which calculates the number of feature other than the i^{th} feature that is to be grooved.

The value of i is the same as stated previously.

There are certain special cases of the rule stated previously. The cases are discussed below.

Case 1

If one of the feature from the i^{th} to the $(i - v)^{th}$ is FORM_UP or SPECIAL_CURVE then grooving of the feature does not take place. The tool path in this case is shown in Fig 4.2a. If in addition

$y_{1u} > (y_{max})_{u+1}$

where u ranges from i to (i-v)

Here y_{1u} = y co-ordinate of the lagging end of the u^{th} feature. The definition of y_{1u} is valid through the rest of this section.

then also grooving of the feature does not take place. The tool path in this case is shown in Fig 4.2b.

Case 2

If one of the feature from the i^{th} to the $(i - v)^{th}$ feature is FORM_DOWN then grooving of the feature does not take place. The path of the tool is shown in Fig 4.2c. If in addition

$y_{1u} > (y_{max})_{u+1}$

Here also u ranges from i to (i - v).

then also grooving of the feature does not take place. The tool path in this case is shown in Fig 4.2d.

The rest of the operations namely external threading (left hand), external threading (right hand), knurling, tapping, forming_up, forming_down, drilling are carried out according to the position of the feature requiring the particular operation from the end of the component or workpiece. In case of the tapping operation drilling operation is performed initially. In case of machining of a finished hole reaming or finish boring operation to be resorted to after the drilling operation in order to achieve the required dimensional tolerance. But knowing when to use which operation is interesting. The reamer size is one limitation, while the other limitation is the length-to-diameter ratio. The reamers are available, in general from 3 to 40mm, if the diameter of the hole to be machined does not fall in this range then boring operation is resorted to. Another consideration is that if the length-to-diameter ratio is less than 2, reaming is preferred to

boring. In our present work the second consideration is incorporated. After all the necessary operations are carried out the part-off operation takes place to separate the job from the blank.

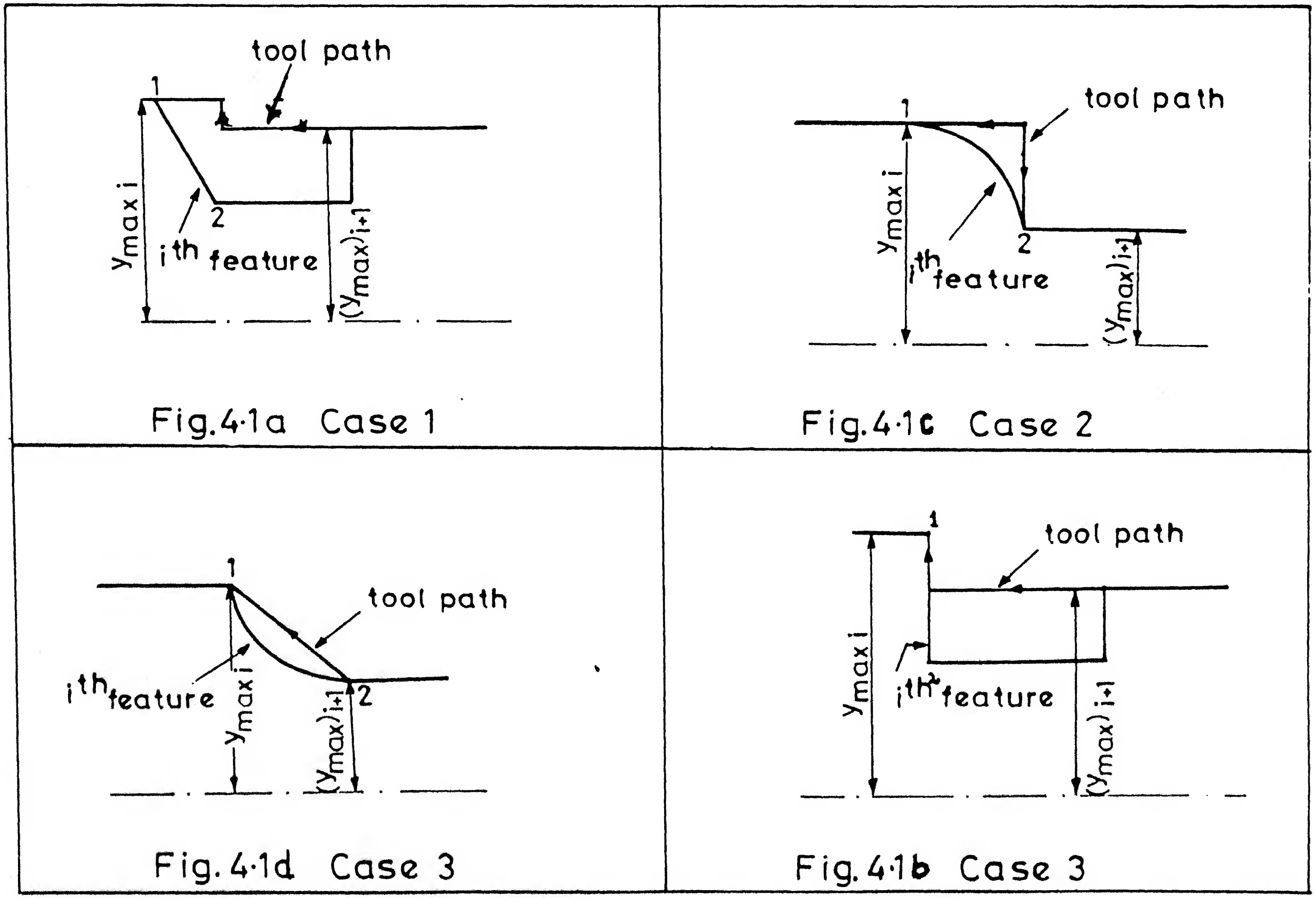


Fig.4·1a Case 1

Fig.4·1c Case 2

Fig.4·1d Case 3

Fig.4·1b Case 3

Fig 4.1 Special cases of turning

Fig 4.2 Special cases of grooving

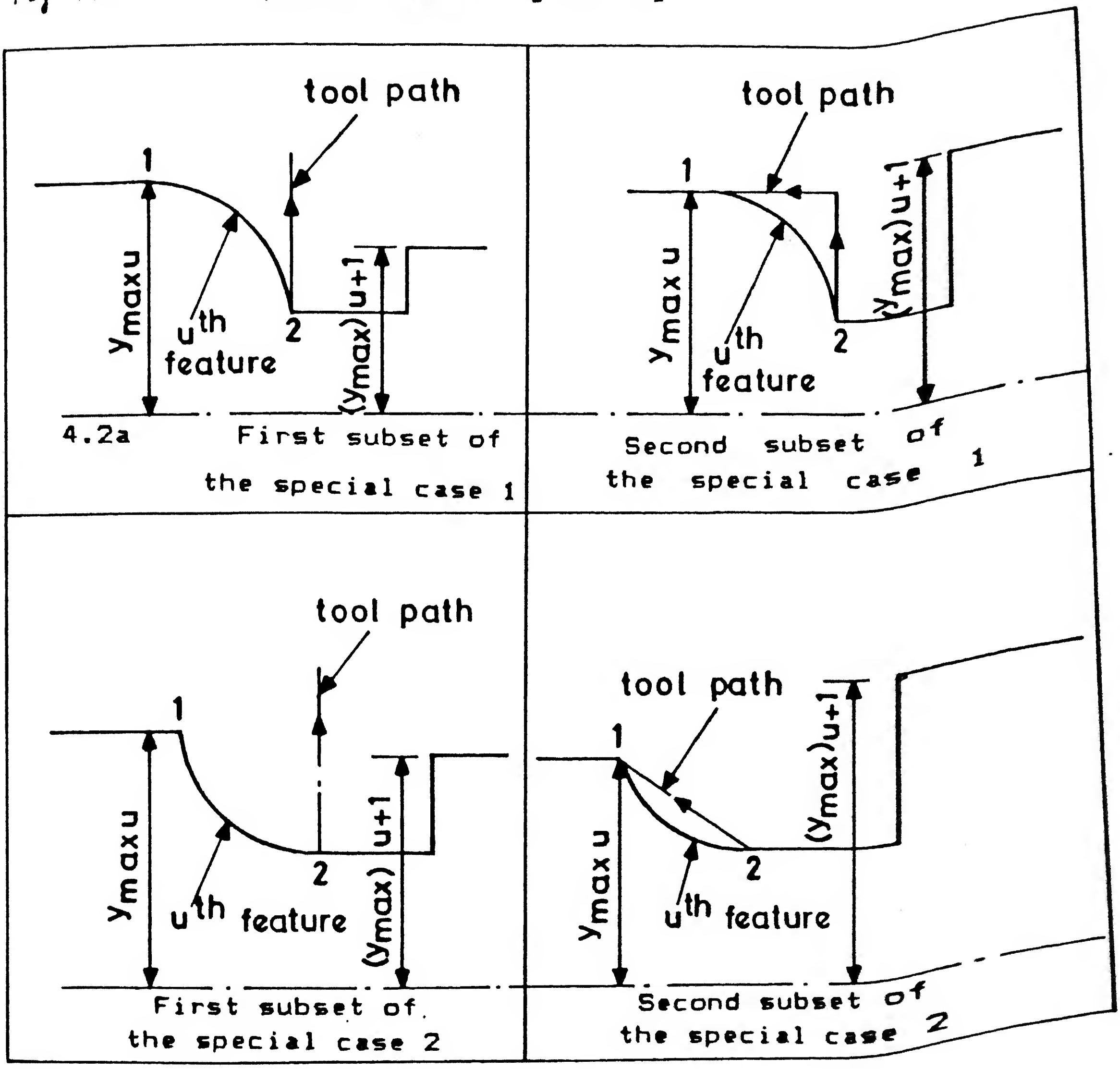


Table 4.1 List of workpiece materials [12]

Material	Hardness Range(H)	Code
Al alloy	70 < H < 105	70105
C20 steel	110 < H < 160	110160
Cu alloy	120 < H < 160	120160
Cu alloy	165 < H < 180	165180
C40 steel	120 < H < 185	120185
Cast iron	150 < H < 180	150180
Cast iron	220 < H < 260	220260
Cast steel	140 < H < 180	140180
Cast steel	190 < H < 240	190240
Alloy steel	150 < H < 240	150240
Alloy steel	240 < H < 310	240310
Alloy steel	315 < H < 370	315370
Alloy steel	380 < H < 440	380440
Alloy steel	450 < H < 500	450500
Malleable iron	160 < H < 220	160220
Stainless steel	160 < H < 220	160220
Stainless steel	300 < H < 350	300350
Stainless steel	375 < H < 440	375440
C80 steel	170 < H < 200	170200

CHAPTER V

NC PART PROGRAM GENERATION

Numerical control part programming is the procedure by which sequence of processing steps to be performed on the NC machine is planned and documented. The person who caries out this planning and documentation work is called the part programmer.

5.1 TYPES OF PART PROGRAMMING Part programming is of two types:

(1) Manual part programming.

(2) Computer assisted part programming.

In manual part programming the part programmer prepares the program and uses the teletype to prepare the punched tape version of the program. In computer assisted part programming the tape is produced by the computer after it has been fed with simple instructions in proper format, which is different from the one used in manual part programming. Manual part programming is only feasible for the relatively simple parts. For complicated parts manual part programming becomes an extremely tedious task and is subject to error. In these instances it is more appropriate to employ the high speed digital computer to assist in the part programming process. The input language to the computer is a universal language akin to English though the final input to the machine tool is identical for all types of machine tool controllers, so the part programmer is not burdened to learn about the peculiarities and specific coding requirement of each NC machine tools, which provides him the ability to handle diverse array of machines and control. The present system uses the second method of part programming but the approach used is different from

the above discussed method as in this case the part programs are generated directly from the information about the geometry of the component.

5.2 NC PART PROGRAM GENERATING MODULE

This module is designed to generate complete NC part programs automatically for axisymmetric components to be machined on an NC turret lathe after receiving the relevant information about speed, feed and blank dimensions from the blank and machining parameter selection module and the necessary information about sequence of operation from the operation selection and sequencing module. The NC part program generated is in word address format and the block length is variable. The criterion for the selection of suitable G and M codes are given in Table 5.1 and 5.2 respectively. For axisymmetric components with complex functional form features this module is equipped with the capability of generating the NC part programs using either linear or circular interpolation depending on the discretion of the user. The above capability is significant since the user has the leverage to find out which method of interpolation fulfills his requirement. Another interesting feature of this module is that in the part input phase the user considers the component to be machined in the X-Y plane but actually the component is in the X-Z plane going by the specification of the machine. This module makes this convertion automatically and the NC part program generated is in accordance with the axis specification of the machine. The details about the axis specification of the machine is given in APPENDIX I.

Table 5.1 Criterion for selection of G codes

G code	Group	Usage
G00	1	For positioning of tool at a rapid speed
G01	1	For linear interpolation(feed)
G02	1	For circular interpolation(CW)
G03	1	For circular interpolation(CCW)
G21	6	For metric data input
G28	0	For returning the tool to the reference point
G50	0	For changing the work co-ordinate
G70	4	For finishing the workpiece turned or grooved previously. This G code generates cycle for finishing the workpiece.
G71	4	For stock removal in turning or grooving. This G code generates cycles to remove material to a predefined contour
G76	0	For thread cutting. This G code generates cycles for machining of threads
G94	1	For stock removal in facing
G96	2	For keeping the surface speed constant. Available as default
G97	2	For cancelling the constant surface speed control.
G99	11	For specifying the feed as per revolution.

Table 5.2 Criterion for the selection of M codes

M code	Usage
M05	For stopping the spindle
M06	For automatic tool change
M09	For putting off the coolant
M13	For starting the spindle and coolant

CHAPTER VI

MACHINING SIMULATION

The simulation of engineering process is based on the idea not to investigate systems directly but with their imitations, with so-called simulation models. With the help of these models, analysis can be made which are not possible on the real object or which are too time intensive and therefore too expensive. Furthermore, simulation models can act as a useful planning aid especially where real systems are lacking (eg. planning for manufacturing systems).

The direct processing of NC data and the presentation of the manufacturing process on a graphic screen by actuating the presentation within short intervals is an ideal example of a simulation model. With this model the exact manufacturing from the unmachined to the machined part can be followed on the screen and hence any faults and deficiencies can be eliminated before the start of actual manufacturing. Control data (e.g depth of cut) can also be verified and optimized if it is deemed necessary.

6.1 PRESENT STATE OF SIMULATION SYSTEMS FOR MANUFACTURING PROCESSES

At present, there are three methods of classification of the present day simulation systems available for manufacturing processes. A brief overview of the three methods are presented below.

The first method of classification is done on the basis of application of the simulation systems. The two subsets of this classification are as follows.

(1) NC-external simulation systems.

(2) NC-integrated simulation systems.

The NC-external simulation systems are very flexible in so far as the place of application is concerned. Their range of application is also large as the same simulation system can be used for different machines of same type without any significant change.

In NC-integrated simulation systems an exact imitation of the manufacturing process is guaranteed as all control-specific algorithms such as NC block or cycle preparation, interpolation and NC-specific machine and tool correction data of simulation are guaranteed. The main disadvantage of NC-integrated simulation systems are their high cost.

The second method of classification of simulation systems is based solely on the geometric consideration. The two subsets of this classification are as follows.

(1) Two dimensional simulation systems.

(2) Three dimensional simulation systems.

The difference between these two subsets lies in the computer's internal presentation and modelling of the geometries of the workpiece and the tool.

The third method of classification of simulation systems is based on time. The two subsets of this classification are as follows.

(1) Real time simulation.

(2) Relation adapted simulation.

In real time simulation the course of the manufacturing time, the simulation systems internal transformation of time and the observer's experience of time of simulation are identical. A

very efficient control unit for displaying and high speed computing are the essential prerequisites for real time simulation as all necessary modelling operations must be done in the time interval of the simulation internal transformation of time. Accordingly the greatest drawback of real time simulation is the high equipment cost.

In relation adapted simulation the movement of the tool is presented in the exact time relation to that which actually takes place on the machine. In this case any presentation of simulation corresponds to one scene of real manufacturing. However, the simulation observer's experience of time does not have to correspond to the real courses of time. The main advantage of relation adapted simulation systems is that the computing expenditure depends directly on the observers wish.

6.2 PRINCIPLES FOR MODELLING THE WORKPIECE

A workpiece modelled results from a boolean operation between workpiece and the tool. Two principles that are widely used for modelling the workpiece is stated below.

(1) Manipulation principle.(2)Generation principle.

In case of the manipulation principle, the modelling of the workpiece projected on a plane is done by overdrawing the background (workpiece) with the contour of the tool. The modelling of the workpiece and the tool is therefore done in the refresh memory directly. The manipulation principle provides with low cost solutions due to the fact that only short computing times and small memory are required. Extensive methods of visualization are not necessary as the content of the refresh memory is already the presentation which has been shown on the screen. The main

disadvantage of the manipulation principle is that its range of application is restricted to the presentation of dynamically balanced parts or projections of parts as only one plane of the workpiece can be modelled in the refresh memory.

In the generation principle on the other hand a modelling on the basis of a geometric model is done in the first step, whereby the model transforms the dimensions of the workpiece in to mathematical structures which can be interpreted by the computer. In the second step, the result of the modelling is presented on the screen by means of suitable methods of visualization. The generation principle can be used for modelling of complex objects. The main disadvantage of modelling workpiece on the basis of generation principle is that large computing time and memory are required, so the operation cost increases.

6.3 MACHINING SIMULATION MODULE

This module deals with the simulation system developed. The simulation system is an NC external simulation system, it is relation adapted and is in two dimension. The workpiece is modelled on the basis of the manipulation principle.

NC external simulation system has been developed in order to increase the range of application of the present system. The system is relation adapted since the primary aim is to give the user the flexibility to choose the system of his liking. In fact the system provides the user three choice of simulation speed. Since the workpiece to be machined is axisymmetric the developed simulation system is two dimensional and the workpiece is modelled on the concepts of the manipulation principle.

The simulation system developed depends on a large

number of data which can be broadly classified in to,

(1) Simulation describing data.

(2) Simulation processing data.

The simulation describing data includes tool descriptions, descriptions of unmachined parts, description of the positions of the axis and the description of the machine by the extents of the working space. Processing data comprises of "dynamic data" i.e the tool path information. As can be seen in Fig 6.1 except for the data regarding the extents of the working space of the machine the other data comes directly from the NC part program generating module. So a one to one correspondence is assured between the operations that takes place on the NC machine and the operations that are shown by the developed simulation system.

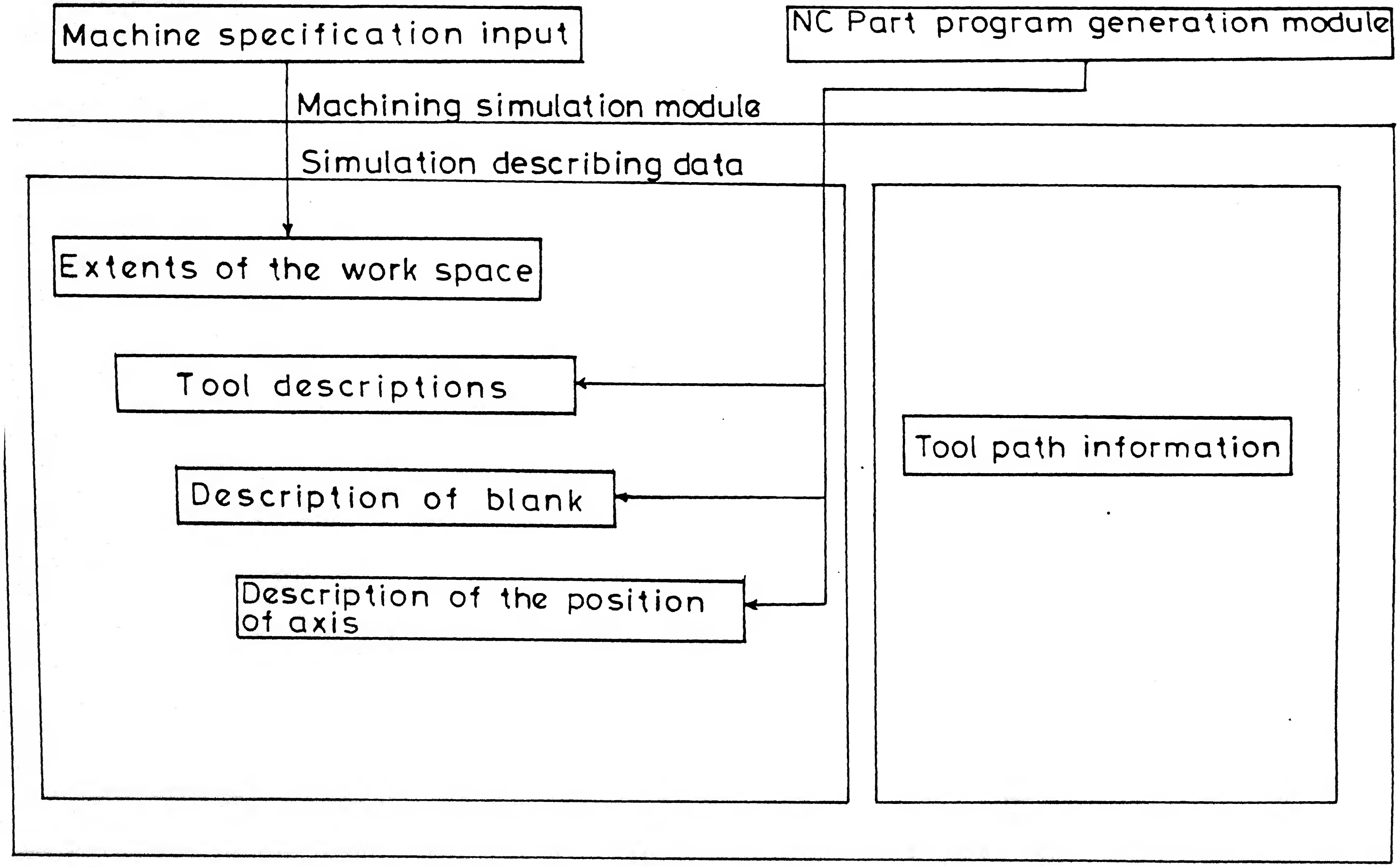


Fig.6·1 Arcitecture of the simulation module

CHAPTER VII

IMPLEMENTATION

The system is developed on an IBM compatible PC XT/AT. The entire source code is written in TURBO C. For simulation purpose the extensive graphics facility of TURBO C has been utilized. The complete software contains a main file, a menu file, a processing file, input files, output files and a number of database files. The file architecture of the system is given in details in Appendix II. Explanation of the functions of each file is given in Appendix III.

7.1 INPUT SPECIFICATION

The inputs to the present system can be grouped under the following two headings

(1) Specifications

(2) Part geometry

7.1.1 Specifications

Specifications include

(a) Machine specifications.

(b) Specifications for the machining of the SPECIAL_CURVE.

(c) Specification for simulating the cutter path on the graphics screen.

Machine specifications include information about maximum travel of tool along x and y axis in mm, maximum feed rate in mm/rev, maximum and minimum speed in r.p.m that is possible on the particular machine tool.

Specifications for machining of SPECIAL_CURVE include

information about the type (i.e. intol or outtol) and value of tolerance and type of interpolation (i.e. straight line or circular) desired by the user.

Specification for simulating the tool path on the graphics screen include information about the simulation speed desired by the user.

The system is equipped to accept the various specifications from the user either interactively or by means of a data file.

7.1.2 Part Geometry

The workpiece dimensions (part geometry) can be given by the user interactively, by means of a data file or by drawing the part geometry in AutoCAD. In the first two modes mentioned above the information about the position and extent of the features that make up the part can be provided by specifying either the co-ordinates of the end points or the two end diameters and the length of the feature (i.e. by primitives). In case of the last mode the above mentioned information are always stored in the form of co-ordinates. If the user decides to give the inputs interactively, the system transfers the data provided by the user to the respective data files so that if the user wishes to change a particular data, he does not have to go through the arduous step of feeding the data interactively from the very beginning. If the user decides to give the part input by drawing the geometry of the part in AutoCAD, the system processes the data exchange file (DXF file) given by AutoCAD for that drawing and extracts the features from the processed data. Since the system is capable of handling part drawn by the two AutoCAD entities arc and line, all simple features and two special features namely FORM_UP and FORM_DOWN can

be recognized directly from the AutoCAD drawing. In case the user wants to give some special features other than the above mentioned ones he is liable to do so by responding to the enquiries of the system about whether he/she wants to change any of the simple feature to special feature. Since the parts handled by the system is axisymmetric the user has to draw only the top half of the part.

While inputing the workpiece dimensions the user has to be very careful in selecting the reference end as all part features are numbered starting from the reference end. To prevent any ambiguity in the selection of the reference end the system provides extensive guidelines to the user. The guidelines are stated below.

1) The reference end can be any of the two ends of the workpiece. It is located such that the distance between the reference end and the edge corresponding to the feature with maximum external diameter is minimum.
2) The part features are numbered from the reference end to the right. The reference end is placed to the left of the part.
3) Features such as internal hole are to be placed at the end other than the reference end.

7.2 AN ILLUSTRATION

To demonstrate certain features of the system, a sample part shown in Fig 7.1 is considered.

The user has to interact with the system at various stages of developing the process planning information. The interaction with the user has been facilitated by defining the predicates as an ASK-USER type. The ASK-USER predicate gets

asserted as fact after accepting the response from the user, but if the user specifies something unrealistic the system warns the user with appropriate error message and asks him to retry.

The ASK-USER predicates for the sample part are given below. Each predicate begins with a question . The users response is indicated after the symbol '>'.

(PLEASE SPECIFY THE WAY YOU WANT TO GIVE THE SPECIFICATIONS)

(OPTIONS AVAILABLE => 1.INTERACTIVELY 2.DATA FILE) >1

** MACHINE SPECIFICATIONS**

(PLEASE SPECIFY VALUE OF MAXIMUM TRAVEL ALONG X AXIS IN mm) >500

(PLEASE SPECIFY VALUE OF MAXIMUM TRAVEL ALONG Y AXIS IN mm) >800

(PLEASE SPECIFY VALUE OF MAXIMUM FEED-RATE IN mm/rev) >5

(PLEASE SPECIFY VALUE OF MAXIMUM SPEED IN r.p.m) >3000

(PLEASE SPECIFY VALUE OF MINIMUM SPEED IN r.p.m) >20

** SPECIFICATIONS FOR MACHINING OF SPECIAL_CURVES**

(PLEASE SPECIFY THE TYPE OF TOLERANCE DESIRED)

(OPTIONS AVAILABLE => 1.INTOL 2.OUTTOL) >1

(PLEASE SPECIFY THE VALUE OF TOLERANCE IN mm) >0.01

(PLEASE SPECIFY THE WAY YOU WANT TO MACHINE THE CURVE)

(OPTIONS AVAILABLE => 1.STRAIGHT LINE INTERPOLATION

2.CIRCULAR INTERPOLATION) >1

** SPECIFICATION FOR SIMULATION OF CUTTER PATH**

(PLEASE SPECIFY THE SIMULATION SPEED DESIRED)

(OPTIONS AVAILABLE => 1.SLOW 2.MEDIUM 3.HIGH) >3

** INPUT OF WORKPIECE DIMENSION BEGINS **

(PLEASE SPECIFY THE NUMBER OF FEATURES) >13

(PLEASE SPECIFY THE WAY YOU WANT TO INPUT THE PART GEOMETRY)

(OPTIONS AVAILABLE => 1.PRIMITIVES 2.CO-ORDINATES) >1

** PRIMITIVE NO => 1 **

```
( PLEASE SPECIFY THE FIRST DIAMETER ) >0

( PLEASE SPECIFY THE SECOND DIAMETER ) >200

( PLEASE SPECIFY THE LENGTH ) >0

( PLEASE SPECIFY THE TYPE OF FEATURE )

( OPTIONS AVAILABLE => 1.SIMPLE 2.SPECIAL ) >1

** PRIMITIVE NO => 2 **

( PLEASE SPECIFY THE FIRST DIAMETER ) >200

( PLEASE SPECIFY THE SECOND DIAMETER ) >200

( PLEASE SPECIFY THE LENGTH ) >10

( PLEASE SPECIFY THE TYPE OF FEATURE )

( OPTIONS AVAILABLE => 1.SIMPLE 2.SPECIAL ) >1

** PRIMITIVE NO => 3 **

( PLEASE SPECIFY THE FIRST DIAMETER ) >200

( PLEASE SPECIFY THE SECOND DIAMETER ) >450

( PLEASE SPECIFY THE LENGTH ) >5

( PLEASE SPECIFY THE TYPE OF FEATURE )

( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >2

( PLEASE SPECIFY THE TYPE OF SPECIAL FEATURE )

( OPTIONS AVAILABLE => 1.PARALLEL_KNURL 2.DIAMOND_KNURL 3.FORM_UP

                       4.FORM_DOWN  5.EXT_THREAD(LH)

                       6.EXT_THREAD(RH)  7.INT_THREAD(LH)

                       8.SPECIAL_CURVE 9.INT_THREAD(RH)) >8

** EQUATION OF THE CURVE SHOULD BE OF THE FORM Y = a1 x F1(X)+..**

( PLEASE SPECIFY THE NO OF TERMS IN THE EQUATION ) >1

( PLEASE SPECIFY THE VALUE OF a1 ) >1

( PLEASE SPECIFY THE FUNCTION F(X))

( OPTIONS AVAILABLE => 1.POWER 2.SIN 3.COS 4.TAN 5.COSEC 6.SEC
7.COT 8.LOG 9.ROOT ) >1

( PLEASE SPECIFY THE POWER TO WHICH X IS TO BE RAISED ) >2
```

```
** PRIMITIVE NO =>4 **
( PLEASE SPECIFY THE FIRST DIAMETER ) >450
( PLEASE SPECIFY THE SECOND DIAMETER ) >450
( PLEASE SPECIFY THE LENGTH ) >100
( PLEASE SPECIFY THE TYPE OF FEATURE )
( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >2
( PLEASE SPECIFY THE TYPE OF SPECIAL FEATURE )
( OPTIONS AVAILABLE => 1.PARALLEL_KNURL 2.DIAMOND_KNURL 3.FORM_UP
                       4.FORM_DOWN  5.EXT_THREAD(LH)
                       6.EXT_THREAD(RH)  7.INT_THREAD(LH)
                       8.SPECIAL_CURVE 9.INT_THREAD(RH)) >5
( PLEASE SPECIFY THE PITCH )
( OPTIONS AVAILABLE => 1) 4.0 , 2) 3.5 , 3) 3.0 , 4) 2.5
5) 2.0 , 6) 1.5 , 7) 1.0 , 8) 0.5 ) >2
** PRIMITIVE NO => 5 **
( PLEASE SPECIFY THE FIRST DIAMETER ) >450
( PLEASE SPECIFY THE SECOND DIAMETER ) >150
( PLEASE SPECIFY THE LENGTH ) >50
( PLEASE SPECIFY THE TYPE OF FEATURE )
( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >1
** PRIMITIVE NO => 6 **
( PLEASE SPECIFY THE FIRST DIAMETER ) >150
( PLEASE SPECIFY THE SECOND DIAMETER ) >150
( PLEASE SPECIFY THE LENGTH ) >35
( PLEASE SPECIFY THE TYPE OF FEATURE )
( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >1
** PRIMITIVE NO => 7 **
( PLEASE SPECIFY THE FIRST DIAMETER ) >150
( PLEASE SPECIFY THE SECOND DIAMETER ) >250
```

```
PLEASE SPECIFY THE LENGTH ) >50
PLEASE SPECIFY THE TYPE OF FEATURE )
OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >1
 PRIMITIVE NO => 8 **
PLEASE SPECIFY THE FIRST DIAMETER ) >250
PLEASE SPECIFY THE SECOND DIAMETER ) >250
PLEASE SPECIFY THE LENGTH ) >50
PLEASE SPECIFY THE TYPE OF FEATURE )
OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >2
PLEASE SPECIFY THE TYPE OF SPECIAL FEATURE )
OPTIONS AVAILABLE => 1.PARALLEL_KNURL 2.DIAMOND_KNURL 3.FORM_UP
                     4.FORM_DOWN  5.EXT_THREAD(LH)
                     6.EXT_THREAD(RH)  7.INT_THREAD(LH)
                     8.SPECIAL_CURVE 9.INT_THREAD(RH)) >2
* PRIMITIVE NO => 9 **
PLEASE SPECIFY THE FIRST DIAMETER ) >250
( PLEASE SPECIFY THE SECOND DIAMETER ) >300
( PLEASE SPECIFY THE LENGTH ) >0
( PLEASE SPECIFY THE TYPE OF FEATURE )
( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >1
** PRIMITIVE NO => 10 **
( PLEASE SPECIFY THE FIRST DIAMETER ) >300
( PLEASE SPECIFY THE SECOND DIAMETER ) >300
( PLEASE SPECIFY THE LENGTH ) >100
( PLEASE SPECIFY THE TYPE OF FEATURE )
( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >1
** PRIMITIVE NO => 11 **
( PLEASE SPECIFY THE FIRST DIAMETER ) >300
( PLEASE SPECIFY THE SECOND DIAMETER ) >300
```

```
( PLEASE SPECIFY THE LENGTH ) >50
( PLEASE SPECIFY THE TYPE OF FEATURE )
( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >2
( PLEASE SPECIFY THE TYPE OF SPECIAL FEATURE )
( OPTIONS AVAILABLE => 1.PARALLEL_KNURL 2.DIAMOND_KNURL 3.FORM_UP
                       4.FORM_DOWN  5.EXT_THREAD(LH)
                       6.EXT_THREAD(RH)  7.INT_THREAD(LH)
                       8.SPECIAL_CURVE 9.INT_THREAD(RH)) >3
( PLEASE SPECIFY THE RADIUS ) >25
** PRIMITIVE NO => 12 **
( PLEASE SPECIFY THE FIRST DIAMETER ) >300
( PLEASE SPECIFY THE SECOND DIAMETER ) >100
( PLEASE SPECIFY THE LENGTH ) >0
( PLEASE SPECIFY THE TYPE OF FEATURE )
( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >1
** PRIMITIVE NO => 13 **
( PLEASE SPECIFY THE FIRST DIAMETER ) >100
( PLEASE SPECIFY THE SECOND DIAMETER ) >100
( PLEASE SPECIFY THE LENGTH ) >50
( PLEASE SPECIFY THE TYPE OF FEATURE )
( OPTIONS AVAILABLE=> 1.SIMPLE 2.SPECIAL ) >1
** LENGTH OF THE WORKPIECE IS => 450 **
( PLEASE SPECIFY THE LENGTH OF THE BLANK ) >454
** DIAMETER OF THE WORKPIECE IS => 450**
( PLEASE SPECIFY THE DIAMETER OF THE BLANK ) >454
** WORK MATERIAL SELECTION **
( OPTIONS AVAILABLE => details of Table 1.1 comes ) >1
** FOR FACING OPERATION **
** RECOMMENDED COOLANT IS => SOLUBLE OIL **
```

```
< MENU1 shown in Fig 7.2 appears >

< Simulation of the cutter path is shown on the graphics screen >

** FOR TURNING OPERATION **

** RECOMMENDED COOLANT IS => SOLUBLE OIL **

< MENU2 shown in Fig 7.2 appears >

< Simulation of the cutter path is shown on the graphics screen >

** FOR GROOVING OPERATION **

( PLEASE SPECIFY THE THICKNESS OF THE GROOVING TOOL ) >5

** RECOMMENDED COOLANT IS => SOLUBLE OIL **

< MENU3 shown in Fig 7.2 appears >

< Simulation of the cutter path is shown on the graphics screen >

** FOR DRILLING OPERATION **

** RECOMMENDED COOLANT IS => **

< MENU4 shown in Fig 7.2 appears >

< Simulation of the cutter path is shown on the graphics screen >

** FOR REAMING OPERATION **

** RECOMMENDED COOLANT IS => **

< MENU5 shown in Fig 7.2 appears >

< Simulation of the cutter path is shown on the graphics screen >

** FOR FORMING_UP OPERATION **

** RECOMMENDED COOLANT IS => SOLUBLE OIL **

< MENU6 shown in Fig 7.2 appears >

< Simulation of the cutter path is shown on  the graphics screen >

** FOR KNURLING OPERATION **

( PLEASE SPECIFY THE LENGTH OF THE KNURLING TOOL ) >14

** RECOMMENDED COOLANT IS => LARD OIL **

< MENU7 shown in Fig 7.2 appears >

< Simulation of the cutter path is shown on the graphics screen >

** FOR EXT_THREADING(LH) OPERATION **
```

* RECOMMENDED COOLANT IS => MEDIUM SULPHURIZED FATTY OIL **

MENU8 shown in Fig 7.2 appears >

Simulation of the cutter path is shown on the graphics screen >

* FOR MACHINING OF SPECIAL_CURVES **

* RECOMMENDED COOLANT IS => SOLUBLE OIL **

MENU9 shown in Fig 7.2 appears >

Simulation of the cutter path is shown on the graphics screen >

* FOR PART_OFF OPERATION **

PLEASE SPECIFY THE LENGTH OF THE PART_OFF TOOL) >4

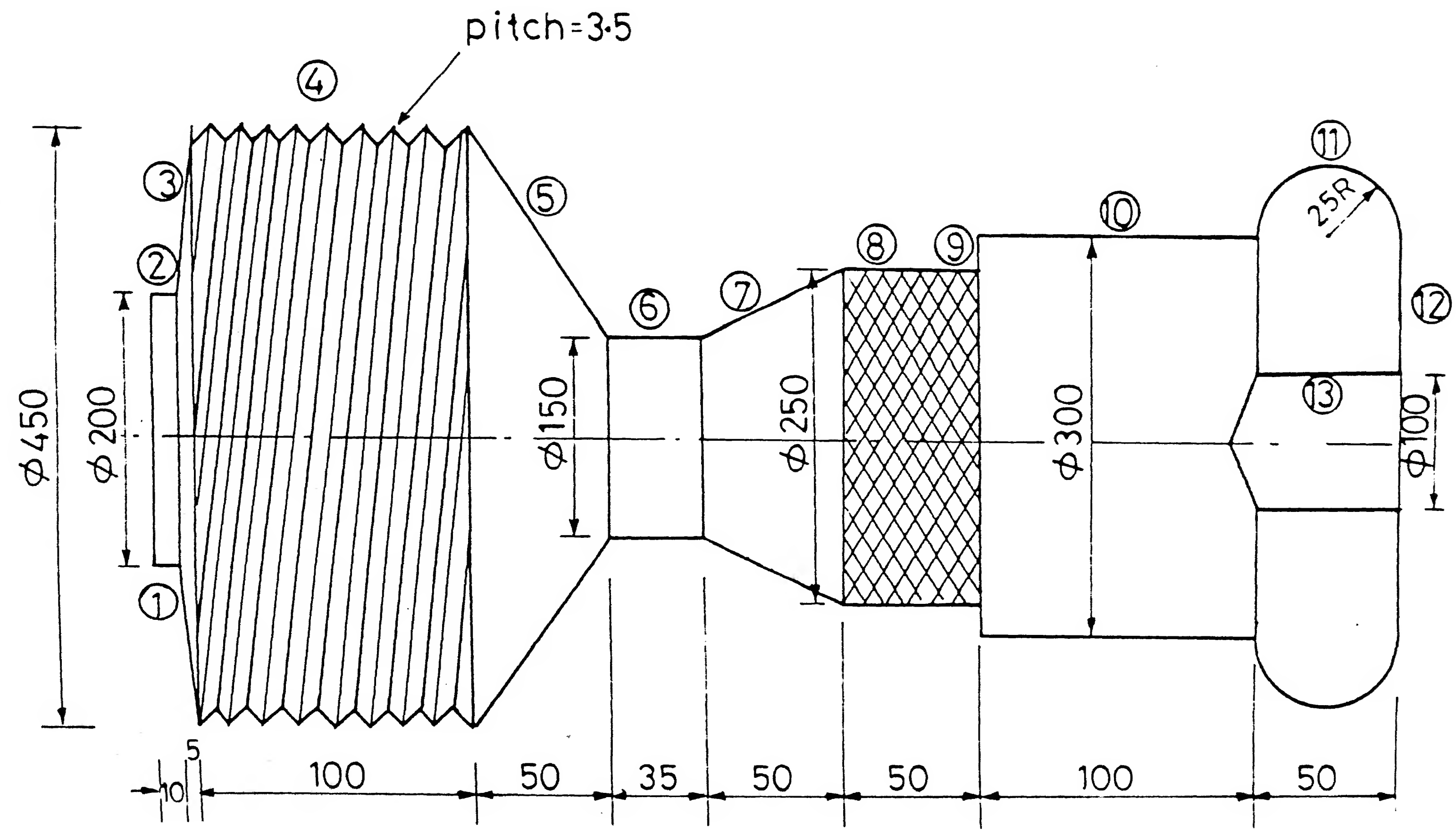
* RECOMMENDED COOLANT IS => SOLUBLE OIL **

MENU10 shown in Fig 7.2 appears >

Simulation of the cutter path is shown on the graphics screen >

7.3 OUTPUTS

The NC code generated and the features recognized after the sample run of the program is given in Appendix IV and Appendix-V respectively.



(All dimensions in mm)

ig. 7·1 Sample part

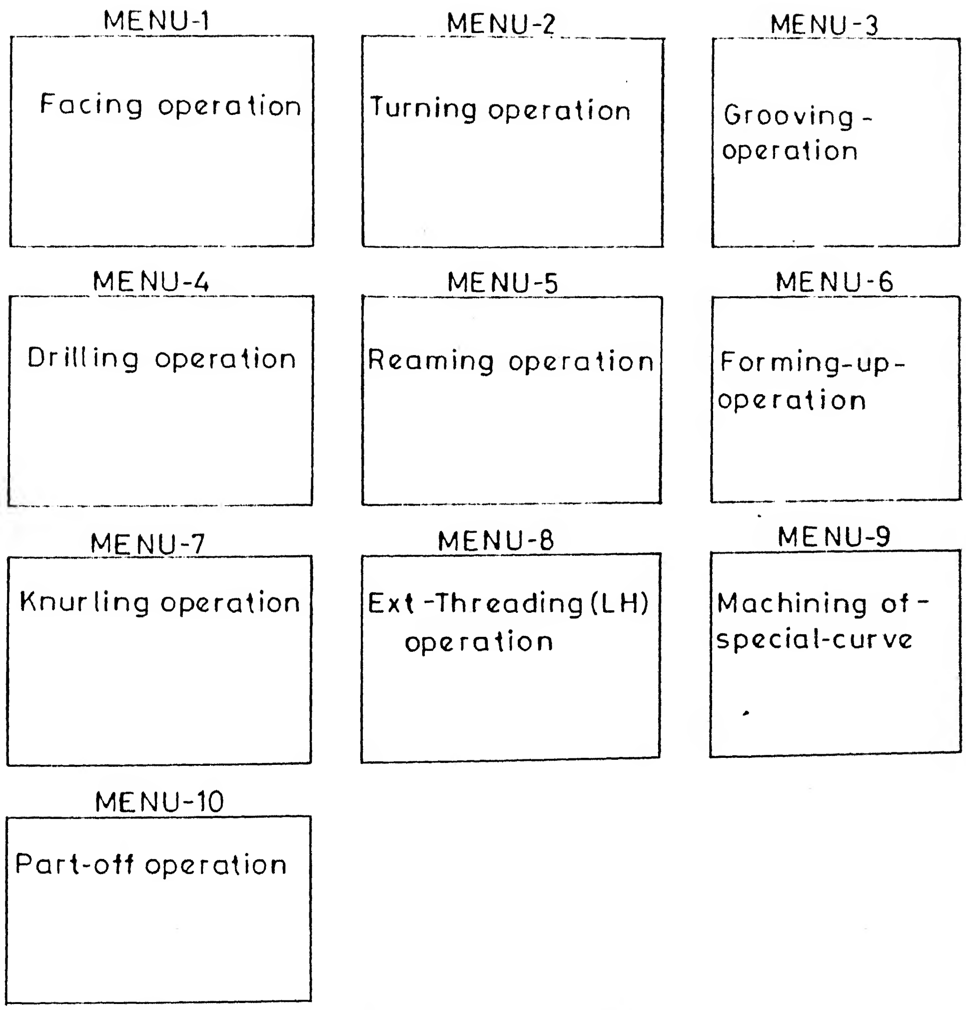


Fig. 7·2 Operation menus

CHAPTER VIII

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

In the present thesis an attempt has been made to design and implement a CAPP system for machining of axisymmetric components. The system extracts the features of the component to be machined from the inputs given by the user, checks the feasibility of the features making up the component and then stores the necessary information in the feature data base. These information are subsequently used to generate the process plan of the component. For generating the process planning information such as speed, feed and coolant various data bases has been. developed. An efficient algorithm has also been developed for sequencing the machining operations necessary for preparing the component. In accordance with the operation sequence NC part program is generated. The system is also equipped with the facility of simulating the cutter path on the graphics screen, this helps the user to have a preview of the machining process that are to take place subsequently. The part program generated is then downloaded directly on the machine tool.

The system is designed to support a gamut of operations that are possible on an NC turret lathe, namely turning, taper turning, facing, grooving, threading, drilling, reaming, boring, tapping and knurling. An important feature of the present system is its capability of machining rotational components with complex functional form features. The system is menu based with multiple hierarchical levels so that the end user finds it convenient to interact with the system.

Though the system developed has a number of outstanding

characteristics, it is no way complete. A number of improvements can still be made. The shortcomings of the present system and the scope for improvement are listed below.

(1) The present system supports operations on axisymmetric components only. Operations on non-axisymmetric components like slab milling, end milling, slot milling and T-slot milling can also be included in the future work. For this the feature recognition module can also be extended to include such features as slots, T slots etc.

(2) A comprehensive tool data base can be linked with the present system so that unmachinable features can be filtered out on the basis of availability of cutting tools.

(3) The process planning module of the present system can be made more comprehensive so as to include new features such as calculation of machining time and determination of production cost.

(4) The number of AutoCAD entities that can be handled by the present system can be increased and the simulation module can also be made more user friendly.

REFERENCE

1. **H. J. Steuden**, "Computer Aided Process Planning: Past, Present, Future", INT.J.Production Research, Vol. 22(2), Feb 1984, pp. 253-266.

2. **L. Atling and H. Zang**, "Computer Aided Process Planning: The State-Of-The-Art Survey", INT.J.Production.Research, Vol. 27(4), April 1989, pp. 553-585

3. **W. I. Bullers, S. Y. Nof and A. B. Whinston**, "Artificial Intelligence in Manufacturing Planning and Control", AIIE Transactions, Vol. 12(4), (1980), pp. 351-363.

4. **A. Kusiak**, "Artificial Intelligence and Operations Research in Flexible Manufacturing Systems", Information Systems and Operationl Research(INFOR), Vol. 25(1), (1987), pp. 2-12.

5. **K. Matsushima, N. Okada, and T. Sata**, "The Integration of CAD and CAM by Application of Artificial Intelligence Techniques", Annals of the CIRP, Vol. 30, (1982), pp. 329-332.

6. **A. H. Van't Evve and H. J. J. Kals**, "XPLANE: A Generative Computer Aided Process Planning System for Part Manufacturing", Annals of the CIRP, Vol. 25, (1986), pp. 325-329.

7. **I. L. Darbyshire and B. J. Davis**, "The Use of Expert Systems in Process Planning", Annals of the CIRP, Vol. 33, (1984), pp. 303-306.

8. **H. P. Wang and R. P. Wyst**, "An Expert System for Machining Data Selection", Computer and Industrial Engineering, Vol. 10(2), (1986), pp. 99-107.

9. **Kripa Shanker and K. V. S. Prasad**, "Intelligent Process Planning: Rotational Parts", **Expert Systems** - Strategy and Solutions in Manufacturing Design and Planning, Society of Manufacturing Engineering, Dearborn, Michigan, Chapter 6, pp. 187-212.

10. **S.R.K. Jasthi, A.V.S.R.K. Prasad, V. Arora, P. N. Rao, U.R.K. Rao and N. K. Tewari**, "Micro-planning in Generative, Interactive, Feature-based and Technology-oriented CAPP System (GIFTS)", Proceedings of the 2nd International Conference on Computer Integrated Manufacturing System, Vol. 2 (22).

11. **D. Batanov and S. Alam**, "From Design to Manufacturing: Feature-Based Approach and Implementation", Proceedings of the 2nd International Conference on Computer Integrated Manufacturing System, Vol. 2 (20),

12. *Production Technology, hmt,* Tata McGraw Hill Publishing Co. Ltd., New Delhi, 1980.

APPENDIX I

AXIS DEFINATIONS

Z Axis => The Z axis is along a line between the spindle and the tailstock or the center of rotation of the spindle. Minus(-) movements of the turret are left towards the headstock. Positive(+) movements are right towards the tailstock.

X Axis => The X axis is 90 degrees from the Z axis(perpendicular to the Z axis). Minus(-) movements of the turret are towards the center line of rotation, and positive(+) movements are away from the center of rotation.

X : X Axis Command

The X word is programmed as a diameter which is used to command a change in position perpendicular to the spindle centerline.

U : X Axis Command

The U word is an incremental distance (diameter value) which is used to command a change in position perpendicular to the spindle center line. The movement is the programmed value.

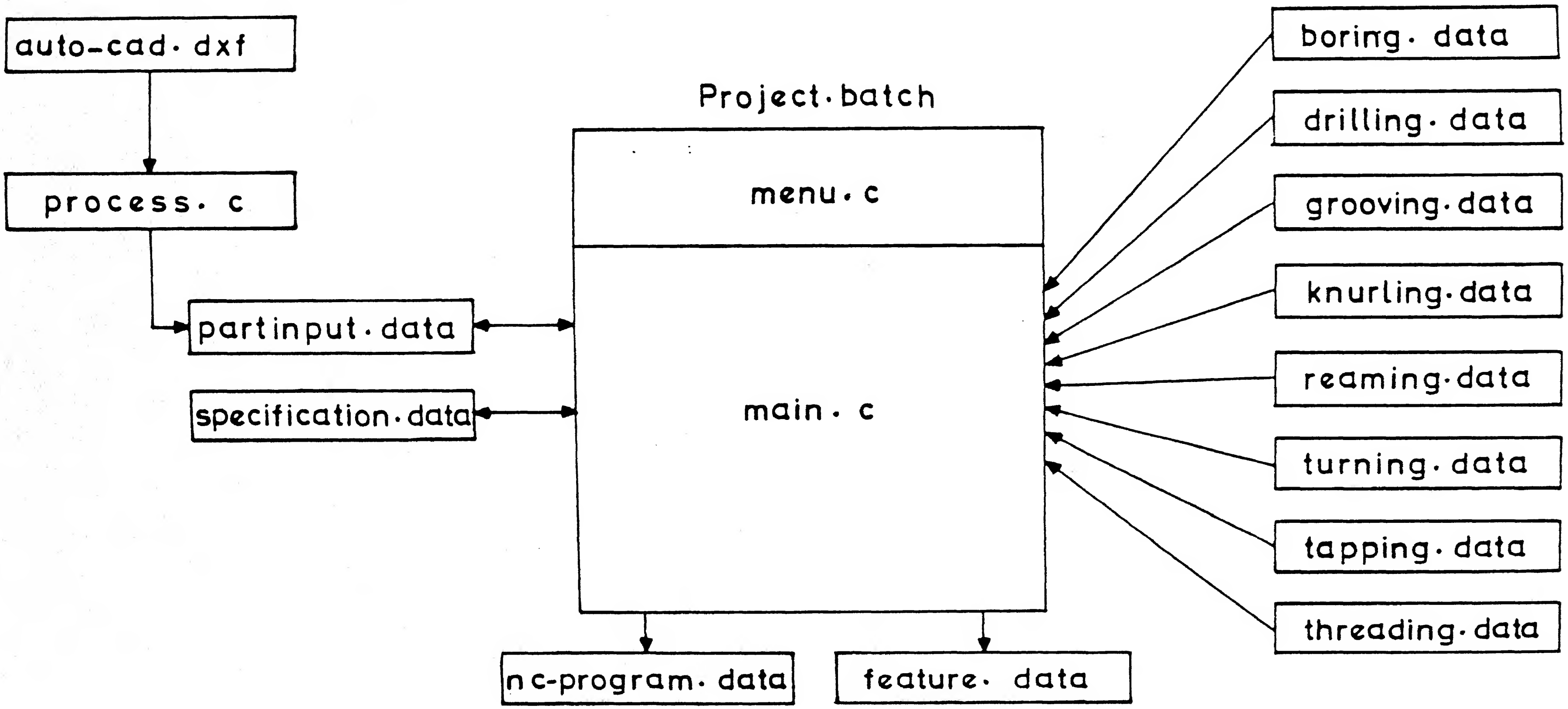
Z : Z Axis Command

The Z word is an absolute dimension which is used to command a change in position parallel to the spindle centerline.

W : Z Axis Command

The W word is an incremental distance which is used to command a change of position parallel to the spindle centerline.

APPENDIX - II


auto-cad·dxf
process·c
partinput·data
specification·data
Project·batch
menu·c
main·c
nc-program·data
feature·data
boring·data
drilling·data
grooving·data
knurling·data
reaming·data
turning·data
tapping·data
threading·data

APPENDIX - III
FILE NOMENCLATUE

Code Name	Actual Name	Description
auto_cad.dxf	auto_cad.dxf	The DXF file of the component drawn by the user in AutoCAD.
boring.data	boring.dat	A data file that contains the data base for the boring operation.
drilling.data	drilling.dat	A data file that contains the data base for the drilling operation.
feature.data	feature.dat	A file that contains the information about the features making the component specified.
grooving.data	grooving.dat	A data file that contains the data base for the grooving operation.
input.data	input.dat	A data file that stores the information of the input part geometry
knurling.data	knurling.dat	A data file that contains the data base for the knurling operation.
main.c	main.c	Main file that generates all the CAPP information.
menu.c	menu.c	This file contains the initial menus of the system.

nc_program.data	nc_prog.dat	This file contains the NC part program for machining the component specified.
process.c	process.c	This file processes the AutoCAD DXF file and passes the necessary information about the part geometry to the file input.dat.
project.batch	project.bat	This batch file contains the files main.c and menu.c
reaming.data	reaming.dat	A data file that contains the data base for the reaming operation.
specification.data	specify.dat	A data file that contains the information of the specification of the machine, specification for machining of the SPECIAL_CURVE and information about the speed of simulation.
turning.data	turning.dat	A data file that contains the data base for the turning operation.
tapping.data	tapping.dat	A data file that contains the data base for the tapping operation.
threading.data	thread.dat	A data file that contains the data base for the threading operation

NC PART PROGRAM OF THE SAMPLE PART AS GIVEN BY THE SYSTEM

```
G21 G99;
G28 U0 W0;
M06 T....;
G50 X... Z...;
** FACING OPERATION **
G97 S2050;
M13 G00 X458.00 Z6.00;
G94 X0.00 Z0.00 F0.30;

** TURNING OPERATION **
G96 S3120;
G00 Z1.0;
G71 U2.0 R0.5;
G71 P10 Q70 U1.0 W.1 F0.21;
N10 G01 X350.00;
N20 X300.000000 Z0.0;
N30 X350.00;
N40 Z-285.00;
N50 X450.00;
N60 Z-335.00;
N70 Z-450.00;
G70 P10 Q70;

** GROOVING OPERATION **
G28 U0 W0;
M06 T....;
G50 X... Z...;
G96 S1514;
G00 X452.00 Z-53.00;
G71 U0.2 R0.5;
G71 P200 Q260;
N200 G01 X300.00;
N210 Z-150.00;
N220 G01 X250.00;
N230 G01 Z-200.00;
N240 G01 X150.00 Z-250.00;
N250 G01 Z-285.00;
N260 G01 X450.00 Z-335.00;
G70 P200 Q260;
G00 X452.00;
G00 X452.00 Z-443.00;
G71 U0.2 R0.5;
G71 P270 Q.280;
N270 G01 X200.00;
N280 Z-450.00;
G70 P270 Q280;
G00 X452.00;

** DRILLING OPERATION **
G28 U0 W0;
M06 T....;
G50 X... Z...;
G00 X0.0 Z1.0;
Z-50.00 F0.25;
```

```
G00 Z1.0;

** REAMING OPERATION **
G28 U0 W0;
M06 T....;
G50 X... Z...;
G00 X0.0 Z1.0;
Z-50.00 F0.21;
G00 Z1.0;

** FORMING(UP) OPERATION **
G28 U0 W0;
M06 T....;
G50 X... Z...;
G00 X452.00 Z0.00;
G01 X334.00 F0.30;
G03 X334.00 Z-50.00 R25.00;
G00 X452.00;
G00 Z0.00;
G01 X318.00 F0.30;
G03 X318.00 Z-50.00 R25.00;
G00 X452.00;
G00 Z0.00;
G01 X302.00 F0.30;
G03 X302.00 Z-50.00 R25.00;
G00 X452.00;

** KNURLING OPERATION **
G28 U0 W0;
M06 T....;
G50 X... Z...;
G00 X452.00 Z-165.00;
G01 X250.00 F0.30;
G01 Z-200.00;
G00 X452.00;

** EXTERNAL_THREADING OPERATION(LH) **
G28 U0 W0;
M06 T....;
G50 X... Z...;
G00 X452.00 Z-335.00;
G97 G76 P021560 Q100 R0.01;
G76 X446.10 Z-435.00 P3898.00 Q0400 F2.50;
G00 X452.00;

** MACHINING OF SPECIAL_CURVE **
G28 U0 W0;
M06 T....;
G50 X... Z...
G96 S1514;
G00 X453.00 Z-440.00;
G71 U0.2 R0.5;
G71 P1000 Q1050;
N1000 G01 X200.00;
N1010 G01 X242.00 Z-439.00;
N1020 G01 X288.00 Z-438.00;
N1030 G01 X338.00 Z-437.00;
N1040 G01 X392.00 Z-436.00;
N1050 G01 X450.00 Z-435.00;
```

```
G70 P1000 Q1050;
G00 X453.00;

** PART_OFF OPERATION **
G28 U0 W0;
M06 T....;
G50 X... Z...;
G00 X452.00 Z-454.00;
G01 X-0.5 F0.30;
G28 U0 W0 M05;
G01 X452.00;
M05;
M09;
```

FEATURES RECOGNIZED BY THE SYSTEM

```
** PRIMITIVE NO-1 **
FEATURE =>UP_FACE
XCORD1 >0.000
YCORD1 >0.000
XCORD2 >0.000
YCORD2 >100.000

** PRIMITIVE NO-2 **
FEATURE =>CYL
XCORD1 >0.000
YCORD1 >100.000
XCORD2 >10.000
YCORD2 >100.000

** PRIMITIVE NO-3 **
FEATURE =>SPECIAL_CURVE
XCORD1 >10.000
YCORD1 >100.000
XCORD2 >15.000
YCORD2 >225.000

** PRIMITIVE NO-4 **
FEATURE =>EXT_THREAD(LH)
XCORD1 >15.000
YCORD1 >225.000
XCORD2 >115.000
YCORD2 >225.000
PITCH >2.500

** PRIMITIVE NO-5 **
FEATURE =>DOWN_EXTAPER
XCORD1 >115.000
YCORD1 >225.000
XCORD2 >165.000
YCORD2 >75.000

** PRIMITIVE NO-6 **
FEATURE =>CYL
XCORD1 >165.000
YCORD1 >75.000
XCORD2 >200.000
YCORD2 >75.000

** PRIMITIVE NO-7 **
FEATURE =>UP_EXTAPER
XCORD1 >200.000
YCORD1 >75.000
XCORD2 >250.000
YCORD2 >125.000
```

** PRIMITIVE NO-8 **
FEATURE =>**DIAMOND_KNURL**
XCORD1 >250.000
YCORD1 >125.000
XCORD2 >300.000
YCORD2 >125.000

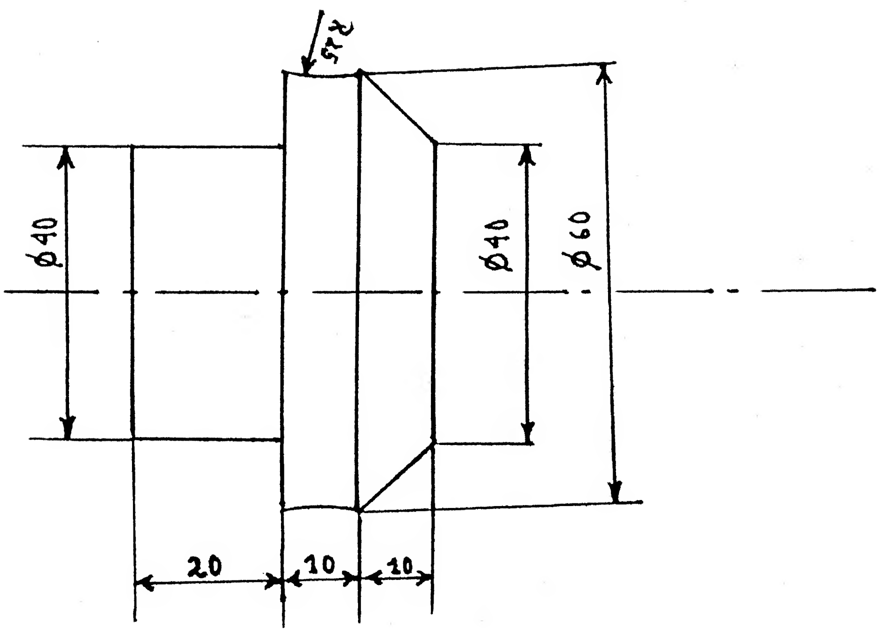
** PRIMITIVE NO-9 **
FEATURE =>**UP_FACE**
XCORD1 >300.000
YCORD1 >125.000
XCORD2 >300.000
YCORD2 >150.000

** PRIMITIVE NO-10 **
FEATURE =>**CYL**
XCORD1 >300.000
YCORD1 >150.000
XCORD2 >400.000
YCORD2 >150.000

** PRIMITIVE NO-11 **
FEATURE =>**FORM_UP**
XCORD1 >400.000
YCORD1 >150.000
XCORD2 >450.000
YCORD2 >150.000
RADIUS >25.000

** PRIMITIVE NO-12 **
FEATURE =>**DOWN_FACE**
XCORD1 >450.000
YCORD1 >150.000
XCORD2 >450.000
YCORD2 >50.000

** PRIMITIVE NO-13 **
FEATURE =>**HOLE**
XCORD1 >450.000
YCORD1 >50.000
XCORD2 >400.000
YCORD2 >50.000


Ø40
Ø40
Ø60
20
10
10